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Play with numbers: participatory design of math learning games

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Play with numbers: participatory design of math learning games

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ABSTRACT
This work applied computer science techniques and technologies to provide tools for the various stakeholders involved in learning disabilities: children, parents, teachers and psycho-therapists. The main idea was to develop engaging games to lead children to do math exercises while having the feeling of playing. These games are especially thought of for children with learning disabilities, paying attention to avoid discriminatory circumstances. Following a participatory design approach, three games were designed with the two-fold goal of increasing math abilities of children and collecting data about their cognitive level and difficulties. Finally, the games were evaluated in a primary school involving a sample of some 60 children. Results are encouraging suggesting that the design approach is suitable and children were enthusiastic about both the games and the design process.

Categories and Subject Descriptors
H.5.2 [**Information interfaces and presentation**]: User Interfaces – *prototyping, user-centered design*

K.3.1 [**Computers and education**]: Computer Uses in Education - *Computer-assisted instruction*

General Terms
Design, Experimentation, Human Factors.

Keywords
Learning difficulties, cooperative inquiry, math facts, dyscalculia

1. INTRODUCTION
Approximately 1 Italian student in 5 encounters difficulties during his/her scholastic career, and if not treated or mitigated these difficulties can heavily affect the student's future. For this reason it is really important to invest time and resources to provide tools and methodologies to all the stakeholders involved in this delicate context. Among various kind of difficulties, we decided to concentrate on math learning disabilities. This paper covers all the concepts at the base of the work and describes the phases we went through during the activity, starting from requirements elicitation, design, prototyping and evaluation. Using participatory design, we involved primary stakeholders in the whole process avoiding the risk to develop something very far from what was really needed and usable by them.

The paper has the following organization. Section 2 reports a literature review about cognitive psychology of learning, going into depth about learning disabilities, a state of the art in educational software and an overview of participatory design techniques with and for children. Section 3 describes the design process we followed with emphasis on the problem analysis, realized through the PACT methodology. Sections 4, 5 and 6 describe educational goals, characteristics, evaluation process and results of the three games realized during the activity. Finally, section 7 reports some guidelines for educational software.

2. LITERATURE REVIEW
Learning is a cognitive process having the feature to be constructive, since arises from the matching between incoming information and stored knowledge. Memory, attention, comprehension ability, reasoning, are the functions more involved in learning. Anyways, they are not enough to guarantee success at school. The student needs also a good motivation, a positive approach, a good awareness of owned skills with the ability to well exploit them [1]. Cognitive psychology of learning takes into account cognitive, metacognitive, emotional and motivational factors, to facilitate learning processes.

Cognitive processes can be defined as representations and mental processes that allow perceiving and elaborating information at the basis of behavior. It is through mental functions such as memory, attention, perception and thought that we can know the world. Mental processes activity permits to transform, reduce, elaborate, store and retrieve information that arrive to our sensorial systems. What we perceive through senses is filtered, elaborate and stored in our memory to be retrieved when is needed by a cognitive function like reading, solving a problem or answering a question.

2.1 Learning disabilities
Difficulties during scholar career are defined as learning difficulties. They can arise from context factors or from mental, sensorial, motory deficits. The term learning disabilities instead, stands for a set of problems related to learning processes [1]. The most agreed definition was given by the National Joint Committee on Learning Disabilities in 1988:

Learning disabilities is a general term that refers to a heterogeneous group of disorders manifested by significant difficulties in the acquisition and use of listening, speaking, reading, writing, reasoning, or mathematical abilities. These disorders are intrinsic to the individual, presumed to be due to central nervous system dysfunction, and may occur across the life span. Problems in self-regulatory behaviors, social perception, and social interaction may exist with learning disabilities but do not by themselves constitute a learning disability. Although learning disabilities may occur concomitantly with other handicapping conditions (for example, sensory impairment, mental retardation, serious emotional disturbance), or with extrinsic influences (such as cultural differences, insufficient or inappropriate instruction), they are not the result of those conditions or influences. [2]

Children with learning disabilities are as smart or smarter than their peers. But they may have difficulty in reading, writing, spelling, reasoning, recalling and/or organizing information in standard conditions. A learning disability cannot be cured or fixed, in fact it is a lifelong issue. With an appropriate support and intervention, however, children with learning disabilities can succeed in school and have a normal life. For instance dispensatory and compesatory actions can be undertaken by teachers and an Individualized Educational Program (IEP) can be developed to better fit student's attitudes and difficulties. Also parents can help children with LD by encouraging their strenght, knowing their issuesses, working with professionals and learning about strategies for dealing with specific difficulties [3].

Dyscalculia is a learning disability in which a person has difficult time solving arithmetic problems and grasping math concepts. According to Temple [4], there are three different form of dyscalculia: dyslexia for digits, procedural dyscalculia and dyscalculia for arithmetical facts, a set of arithmetical procedures that do not need calculus processes. In fact, the results of an arithmetical fact are already present in memory and have to be retrieved in response to the stimulus. For example, we know that "5 + 3 = 8" without reasoning, we just know it and hence the process is very fast. The continuous repeating of arithmetical facts allows children to store them into their semantic memory, reaching a high level of automation. In other words, there is an immediate recovery of information in an effortless way, using low cognitive resources.

Difficulty in learning arithmetical facts can be correlated to a more general difficulty in creating memory associations or mechanical storing of sequences of symbols. There are several strategies to improve arithmetical skills, exploiting the association to figures or sounds but any attempt have to be associated with a high number of iterations. Anyways, since the exercises can be boring or even frustrating it is fundamental to consider factors like empathy, motivation increasing, interaction and socialization [5].

2.2 Software for teaching math

There are a number of didactical software, especially for logical and math skills enhancement. Often these software are classified as games but they are actually an interactive version of standard exercises without a playful component Very often there are no strategies given, no engagement provided, so only those who already loves math or who are forced are likely to play. Furthermore, a high percentage of available software is suitable for students who already have abilities, but since they have been designed without taking into account needs and requirements of children affected by LD, they could be ineffective and we think they could potentially be counterproductive. In fact, on the basis of our observations and expert opinions, such games stress the gap between people who have some difficulties and those who have not.

There are also technologies specifically thought for math LD and among them there are some designed to improve fluency in arithmetical facts. Although it seems intuitive that using technology in a drill-and-practice format helps student develop the declarative fact knowledge, evidence suggests that this is not the case. The main cause of failure is that typical drill-and-practice software is designed in such a way that students practice "procedural counting" strategies instead of developing the ability to recall facts from memory [6].

Hassebring and Goin (2005) developed an intervention paradigm called FASTT (Fluency and Automaticity through Systematic Teaching with Technology) to assist students in the development of declarative fact knowledge. The key to making the retrieval of basic arithmetical facts fluent is to establish a mental link between the facts and their answers which must be stored in long term memory through a regular use of the program. In the same period, Cornoldi (2005) developed a methodology called Memocalcolo (Figure 1) that is centered on arithmetical facts learning.

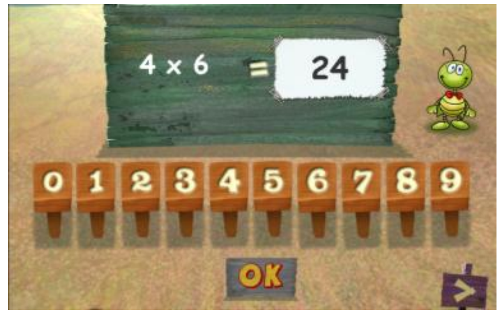

Figure 1: screenshot taken from Memocalcolo

The contribution of this paper is to exploit the proven effectiveness [6] [7] of the fundamentals of these methods, making them more suitable and enjoyable by children. In fact, the weakness of current solutions is that children are not really enticed to continuously use the software, compromising their effectiveness. Often, children have to be forced to use the tools and under certain circumstances this could represent a serious obstacle.

2.3 Participatory design with children

Design is a practical and creative activity, the ultimate intent of which is to develop a product that helps its users to achieve their goals [8]. Participatory design can be described, in its simplest form as actively involving the stakeholders in such a process. It is a design philosophy in which the needs, goals, and limitations of end users of a product are given high attention at every step of the design process. In other words consists in putting the final user in a crucial role during the whole process instead of intuitively try to fulfill his/her requirements and expectations [8]. Participatory design is a form of user-centered design, where different stakeholders are involved as active members in the design team [9]. What characterizes it is to cover situations where there is more than one category of individual involved in the collaboration. Standard methods that concern the design of new technologies or informatics systems cannot always be applied in a stiff way but rather they have to be adapted and mediated on the basis of the field of application. This happens in particular when the main stakeholders are children because working with this category of people is very different from usual

Children are emerging as frequent and experienced users of technology, and there is a growing market for children's computing products and packages. Involving children in participatory design activities is an opportunity to better understand their needs and issues. In fact, children have their own likes, dislikes, curiosities and needs that are not the same as their parents or teachers. As obvious as this may seem, we as designers of new technologies for children sometimes forget that young people are not `just short adults' but an entirely different user population with their own culture, norms and complexities [9].

It is common for developers and designers, to ask parents and teachers what they think their children or students may need, rather than directly asking them [10]. This may be due to the traditional power structure of the "all-knowing" adult and the "all-learning" child. In addition, we as designers have our own biases and assumptions about children. We may also have our own preconvinced notions about learning theories and educational strategies due to the many years of school experience [9].

We cannot expect very young people to know what educational goals need to be covered in a school curriculum, but we can expect children to tell us what excites and bores them, what helps them learn, and what can be used in their homes or schools. Furthermore, children are very honest and direct and are very good at asking "Why not?". They force us adults to keep questioning and to revise our mindset and point of view.

2.3.1 The role of children in designing technologies

Children, especially if young, have a more difficult time verbalizing their thoughts, mostly when it concerns abstract concepts and actions. So they could behave in ways that we, as adult, cannot understand giving raise to difficulties and obstacles in the design process in all its phases. According to Druin [9], there are four main roles that children can play in the technology design process: user, tester, informant and design partner. These roles are not necessarily different from those that can be played by adults, but the methods and contexts can be very different. In the role of user, children contribute to the development process by using technology, while adults may observe videotape or test for skills. Researchers use this role to try to understand the impact of existing technologies on child users, so future technologies can be changed. In the role of tester, children test prototypes of technology that have not been yet released to the market. As a tester, children are again observed with the technology and/or asked for direct comments concerning their experiences giving feedback for the improvement of usability or design. Also impact on children of new technologies can be assessed, and adults can ask directly to children questions about desired features, or about their feelings and experiences. A very important aspect for our work is the possibility to understand if children can learn with the technology. In the role of informant, children play a part in the design process at various stages, based on when researchers believe children can inform the design process. Before any technology is developed, children may be observed with existing technologies or they may be asked for input on design sketches or low-tech prototypes. Once the technology is developed, children may again offer input and feedback. Low-tech materials, interviews and design feedback on prototype can all be used as methods for informants. Finally, in the role of design partner, children are considered to be equal stakeholders in the design of new technologies throughout the entire experience. As partners, children contribute to the process in ways that are appropriate for children and process. They have special experiences and viewpoints that can support the design process that other partners may not be capable of contributing. The most important goal of this type of partnership is idea elaboration.

2.3.2 The IBF Participatory Continuum Model

Participatory design can describe a range of approaches within collaborative design. The amount of participation by the design experts and domain experts is not static. Participatory design is a continuum along which there are identifiable, but not discrete, modes. These modes are delineated by the amount of domain expert (in our case children) contribution to the design. According to Read we can call these design modes Informant, Balanced, and Facilitated [11].

Informant design assumes that the domain expert's contribution is largely limited to informing the design experts, and that the design is mostly realized by the design experts. We can compare this contribution level to the role of informants expressed by Druin. Balanced design assumes an equal partnership between the two categories of participant, both engaged in informing and realizing the ideas. This could be the contribution level of children when involved as design partner. Facilitated design puts the emphasis onto the domain expert both to initiate ideas and to take the lead in realizing the design, with the design expert being in a facilitating role. It seems there is no clear correspondence with any among Druin's roles.

2.3.3 Cooperative inquiry

It is very difficult to actively involve children in an effective way because of biases and different mindsets. In fact the ability to change the way to set expectations, brainstorming and reflection as a team is required. This ability, according to Druin again, is called cooperative inquiry [12]. What cooperative inquiry brings to the human-computer interaction research is a set of methods specifically created for working with teams of children and adults.

Low-tech prototyping is a technique in which children and adults use traditional arts supplies as glue, colors, paper, scissors and so on, to create low-prototypes of technology. This method can help involving children in the design process, becoming a bridge for communication between them and adults. Children are grouped by 2 or 3 and they present to all their artifacts that are evaluated by the team. Sticky note affinity analysis method instead allows children to express their opinion through writing down on sticky notes what they like or dislike about prototypes or ideas. Once notes are written, they are collected and given to an adult that places them on a wall space. The leader groups notes into categories and the outcome is a frequency analysis that will be used for the next iteration of a technology [13].

2.3.4 Measuring children's fun

Children are not the same as adults, their motivations are different, and they have different desires and expectations. In 1999, Druin et al stressed that children have their own environments that adult researchers need to understand. This is not only essential when we design for children, it is also important when we use children to evaluate products [13]. Fun is a concept strictly related to children, although it is not a usability metric. It can be a descriptor for user's experience and also a requirement. Fun and usability are parallel features, because a product cannot be fun if it is not usable. Especially when working with and for children, fun is a crucial parameter to measure the goodness of the design's outcome. Hence, it is important to measure fun during the evaluation phase. Read illustrates that fun can be considered to have three dimensions: expectations, engagement and endurability.

Typically, during an interaction design process there is a frequent use of surveys and they rely on the use of a question and answer process. Asking good questions is not easy, and for some children, understanding and interpreting the question, and formulating an appropriate response can be very difficult [14]. There are a lot of factors that can influence the reliability of the answers especially when children are involved: language ability, reading age, motors skills, confidence, self-belief and the desire to please. Read gave some guidelines including keeping questionnaires short, piloting the language, limiting the writing and using appropriate methods.

3. DESIGN PROCESS

There are four main activities that characterize interaction design methodology. These activities are reiterated to refine the final outcome on the basis of the evaluations and with the constant involvement of the stakeholders

- Identifying needs and establishing requirements: to satisfy the goal of providing solutions to support people in their activities must be clear in mind who the users are and what they want (which are their goals).
- Developing alternative designs: the core activity of designing, suggesting ideas and proposals for meeting the requirements elicited in the previous step. Alternatives

should be always considered. There are two sub-activities: conceptual design and physical design.
- Prototyping: it is basically a representation of a design before the final artifact exists and allows going from the conceptual design to the physical design. A prototype is not a refined and finished product, it is simply a model and has the aim of evoking reactions from the stakeholders during the process and not at its end. Prototypes are thought for specific goals.
- Evaluation: it consists mainly in measuring prototypes' acceptability from various points of view. There are several techniques available, such as observations, questionnaires, and interviews.

The pattern described above is the one we adopted in our design. At the beginning domain experts were involved through interviews and documentation was studied, including fundamentals of cognitive psychology of learning, learning, disabilities, and interaction design with children. A big effort was put to understand the school environment with its roles, rules, schedules, due dates and stiffness.

The first activity with the children was a passive observation during two standard class activities in which children used some didactical software. We understood that children tend to be very influenced by their friends (for instance in the game choice). They are also very competitive; they continually exchange information about number of right answers and so on. They changed game very often, as soon as they encountered the first obstacles in understanding or answering, they passed on to another game. When we asked them which were the selection criteria for the game to play, they answered: "the icon" or "the colors".

Once a sufficient knowledge of the background was acquired, we started to design low-fidelity prototypes (hand-made drawings), to have discussions with domain experts to verify the validity of the ideas and to elicit basic requirements. In this phase the stakeholders were psychologists, therapists and educators. On the basis of the first feedback some games were developed with Scratch. These first versions of the prototypes can be thought as medium-fidelity because they had the aim of permitting evaluators to better understand the behavior, responses and appearance of the games. Continuing this reiteration process of design, prototyping, evaluation and redesign, led to three medium fidelity prototypes ready for final testing.

For one of the games, a full-fledged participatory process was followed, involving children in cooperative inquiry activities, hence they actually played the role of design partners. For the other two games, children were involved as testers because the previous approach was too challenging in terms of time. With respect to evaluation by final users, we used three methods:

- Observation: observing children during the game sessions to collect information about feelings, behaviors, reactions, participation and distraction.
- Questionnaires: specifically designed for children to elicit engagement, endurability and fun but also new ideas, suggestions and feelings.
- Log: the games were programmed to collect data which were used off-line to reason with teachers and psychologists.

3.1 Problem analysis

This section presents a PACT analysis to orient early design. "P" stands for people (users and stakeholders), "A" stands for activities: what is supposed to do with the system? "C" stands for context: where does the interaction occur? Finally, "T" stands for technology, which ones will be involved for the implementation of the solution. It should be noticed that this activity was done in Italy, so the analysis of processes and people could be different if conducted in other countries.

3.1.1 People

There are several stakeholders involved in the project at different levels:

- Children: they are the main stakeholders because they are the hubs of the whole process. All the other users act in their function, and the system could have a positive impact on their life. Of course, we are mostly speaking about children with learning disabilities but all children can be involved as stakeholders. Children are confident with technology and are very attracted to it. They tend to make many comparisons with their peers as an assessment to their value, they are influenced by a lot of factors, especially what their peers do or say. Since children with LD have difficulties in interpreting symbols and writings used in games, there are some design principles to follow in order to mitigate the problem [15].
- Medical and clinical staff: this category includes psychiatrists, psychologists, pediatricians and neurologists. They are all involved in the process of diagnosis, addressing and monitoring children's learning disabilities. They need a lot of information and data about children, and have to keep track of the clinical and school history for each child. However, they are involved only if parents decide to resort to them typically after being alerted by teachers. For this reason, medicals can ignore some LD existing cases.
- Teachers: they are responsible for children in their class. They have to be careful to notice whether a child shows possible LD symptoms. They have relationships with parents and can suggest them to have an interview with the medical person responsible for preliminary diagnosis. During classes they use a lot of methodologies and tools to support teaching and always need to be up to date with children expectations and changes.
- Special needs teachers: they are associated to one or many children with LD and need instruments and methods, depending on the specific attitudes and difficulties of the child. Among these figures there is a coordinator that represents the school when speaking to medicals and parents. He/she decides the best way to act for each child.
- Parents: they are involved in an indirect way but are very interested in whatever can allow their children to improve their own abilities. They are also interested in tools to exploit their relationships with children.

Most of the stakeholders (except children) are characterized by low computer skills. Furthermore, mostly teachers and therapists are relatively aged people and are usually not very interested in technology.

3.1.2 Context

This activity is inserted in a project of Trento's province (Italy) called CARIN that aims to develop a health-based social network to facilitate information and communication management in neuropsychiatric context. More specifically speaking, the context has to be meant as where and when these games will be used.

3.1.2.1 Physical context

The place could be school or home, but also everywhere through a smart phone, or in the attendance room of a medical. This means that the chosen technology has to be cross-platform and cross-device.

3.1.2.2 Social context
These games are thought to be used individually by children with LD, by all the students during a classroom activity, or by a child with an adult. They have to be designed to avoid discrimination between children. In fact, what usually happens is that children with LD have to use special games that make them feel as "different" from the others, with the risk to lower the child self-esteem.

3.1.2.3 Psychological context
Games have to be fun and engaging to get children exercising. They should leverage on token economy techniques that exploit "tokens" to enhance motivation [16]. These tokens are something valuable for children that can be earned by playing the game and making exercises. Doing so he/she will be stimulated to engage in the game to have a return in terms of self-esteem, satisfaction and gratification from teachers and peers. Children are usually evaluated on the basis of their scholastic outcomes, so children with LD will never be able to compete with their colleagues. Hence, games that break this trend and give different ways to evaluate and measure children could be useful to give disadvantaged students a chance to redeem themselves.

3.1.3 Activity
The main goal of this work was finding scenarios for arithmetical facts reiteration. We thought of three games with different pedagogical purposes. The games have in common the main goal and the methodology. Basically the intuition was to exploit engaging games to force children to make arithmetical calculi. So operations are never the main subject of the activity, rather they are something that can help to go ahead in the game. Children should have the perception of playing rather than making homework. These games should be able to collect a lot of interesting data for all the involved stakeholders, such as the number of executed calculi, average response time, percentage of correctness (total and per calculus), improvements, earned points and so on. These data should be published on a web platform with different level of access and used for both monitoring and diagnosis. Normally when a child is suspected to have a LD, he/she is asked to make some specific tests with a therapist, but there is a high risk of bias, because of emotional and other factors. Furthermore, if the teacher (who usually notices the problem) makes an evaluation mistake, the involved child could be deprived of the support and treated as "normal" for several years, with heavy consequences on education outcome and self-esteem. In conclusion, this kind of games could be used as a preliminary test for all the children, avoiding biases and discriminatory problems.

3.1.4 Technology
One of the main characteristics that a tool for the realization of prototypes must have is learnability: you cannot spend too much time to learn how it works. Furthermore, it must allow creating and modifying artifacts easily. To respond to these features and also because of the school context, Scratch was chosen as the development environment for the games as it is simple to create small animations and interactive games, and to publish projects online. As last but not least, it is free.

Scratch is a computer language learning environment enabling beginners to get results without having to learn syntactically correct writing [17]. The first version was developed in 2006 by the Lifelong Kindergarten group, led by Mitchel Resnick, at the MIT Media Lab [18]. Basically it is based on graphical blocks to be used in place of lines of code. Hence, almost everyone can put hands on the source code to customize an application, modifying parameters or images. This is indeed a key feature because of the aforementioned lack in computer skills of adult stakeholders.

3.2 Design criteria
On the basis of the problem analysis and the literature review, some specific design criteria were adopted. These are common for all the games, so they will not be repeated in the specific sections. First of all, we decided to develop games, not didactical software dressed up as a game. Hence, we made large use of levels, points, lives and whatever helps children to believe they are playing. Calculi were integrated within the games and used to earn points, to avoid losing a life, to make an enemy harmless and so on. In practice, math was used as a weapon or a tool to go ahead in the game. For this reason one of the most important user-experience criteria was playability, and we invented really simple games. There are some common features/concepts at the basis of FASTT and Memocalcolo that were taken into consideration:

- Identification of fluent and non-fluent facts through measurement of correctness and response time.
- Restricted presentation of non-fluent information: once a calculus is solved within a certain time, it is removed from the list of calculi.
- Use of challenge times: each child can answer within a personalized time, based on his/her abilities.
- Use of drill-and-practice: reiteration of calculi.
- Monitoring of student performance: everything is logged and made available to stakeholders.

The games use calculi picked from a list of particularly meaningful arithmetical facts (taken from Memocalcolo). Calculi are repeatedly asked in a random way, giving the user a certain amount of time to answer. If the answer is wrong, the game displays the solution for some seconds, to help the child to memorize the math fact. In particular, the calculus is always written as a complete string, because children are advantaged in memorizing it in that form (e.g. "4 x 4 = 16"). To avoid discrimination, we thought of a special feature: at the beginning of the first game, the child is asked to make a training session to get confident with the interface and the keys, solving some calculi. He/she is invited to take it seriously and is awarded some points. During this training session, the application records all the results and response times and tunes a set of parameters on the basis of acquired data. These parameters make the game and the calculi easier or harder depending on the math skills of the child. Doing so, there is a sort of compensation, and during a classroom session could happen that a child with LD will be able to earn more points than a "normal" one. In practice, he/she will not be measured on his/her absolute abilities but in a relative way. Children are not aware of this compensation mechanism.

Standard design principles like usability, consistency, affordance and visibility were taken into consideration. For example, the keyboard to input results is very similar to a cell phone's one and it is equal for all the games (horizontal consistency). When a message is shown, all the other objects are hidden to facilitate the concentration on the writings. Initial instructions are clear and suggestions are given during the game to help children discovering all the possible strategies. Since we are mainly focused on children with LD, there are some specific design principles we followed. Most children with LD are distracted by too much stimuli coming at the same time, so we designed very simple screens with very few indicators (in two cases just one).

The games were designed in a parametric way, so it is really simple to change times, speed, characters, calculi and other variables. In this way teachers and educators can set up the application properly. The increments between levels are small, to encourage children with LD to go ahead. When a calculus is missed, the game does not ask to retry it soon, but it will be re-asked in another time, to avoid creating frustration.

4. GAME 1: "STAY ALIVE"

4.1 Educational goals

These are the specific goals for this game:

- Making exercises with arithmetical facts to improve children fluency through a high number of iterations.
- Helping children to be more confident with math, using it as an helpful tool to exit critical situations. Math can become a sort of safety device to invoke when needed.
- Providing an engaging game to be used by the whole class as a math activity.
- Measuring children attitudes and abilities such as strategies adoption or coordination between keyboard and mouse.

4.2 Game description

"Stay alive" was inspired by other existing games. The basic idea was that educational games have to be easy to learn and understand. For instance, classical games like "arkanoid" or others could be really suitable for this purpose. The attention of the child has to be easily transferred to the calculi and it could not be possible if the game is too complex. Furthermore, the game could be used also on a cell phone or during brief school activities, complex games are not adapt for such scenarios.

In practice the game consists in a ball that has to avoid big barricades with some openings, coming from various directions and crossing all the game field. The player pilots the ball using the keyboard. At the beginning the barricades appear one at time, but during the game they increase speed and number. "Stay alive" needs ability in dodging obstacles because in case of impact the player loses. During the game some objects appear on the display and if caught by the ball they give more speed for some seconds or points (Figure 2). This makes the game quite varied. When a certain amount of time is elapsed, a writing appears and advises about the passing to a new level. Points are continuously increased in proportion to the elapsed time.

Figure 2: screenshot of a game phase

The player can either choose to only use his/her ability to dodge barricades or to resort to math. In the latter case there are two different ways. If the player clicks on a barricade, the game pauses and a completely new screen is displayed (Figure 3). A calculus is asked and the player has to answer using a big keypad with the mouse or the keyboard. He/she has to answer within a certain time otherwise it is considered as a wrong answer. If he/she gives the right answer, the clicked bar changes appearance and becomes harmless for some seconds. The other chance is to press the spacebar on the keyboard and another calculus is asked in the same fashion. In this case, if the answer is right, all the barricades stop for some seconds, allowing the ball to escape in a safe position. In any case, if the calculus is correct the player earns some points.

What usually happens is that at the beginning the child tries to dodge the bars moving the ball but at a certain point it becomes too difficult or even impossible and he/she is bound to resort to one of the two mathematical tricks. Once the player realizes that he/she can take a big advantage and gain points, he/she will often use tricks. In this way the child plays and makes calculi without being bored or frustrated, also because of the compensation method that tunes the difficulty level to his/her actual abilities.

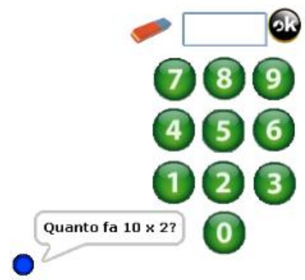

Figure 3: screenshot of the calculus phase.

4.3 Evaluation

Two different evaluation sessions were conducted with the following goals: assessing the playability of the game, debugging the application, measuring reactions, feelings, fun and engagement, testing reliability and effectiveness of the compensation method, testing the usability of the interface, assessing the suitability of the tricks, finding relationships between math capabilities and resort to calculi.

4.3.1 Procedure

Two different classes were involved. The first one was composed of 19 ten year-old children (1 with LD and 1 with hyperactivity disorders) and the second one of 18 nine year-old (2 with LD). We explained them the real aim of the activity and that they had a crucial role. Both teachers and students were excited and collaborative and the sessions were not difficult to manage.

The first class had to play "Stay alive" (provided with the compensation method) for half an hour. We took notes about concentration, doubts, difficulties, possible improvements, things to change and so on. At the end children were asked to answer a questionnaire, with the recommendation to be honest. Finally, they were thanked for their important contribution.

The second class played without compensation. The assessment had the additional goal to compare "Stay alive" (S) with an existing game picked up from Memocalcolo's CD (M). In particular we were interested in comparing attention and concentration using the two software and the correlations between the performances. Children were divided into two groups to avoid biases. One group was asked to play with M first and then with S, vice versa for the second group. "Stay alive" was programmed to propose the same calculi of M with a comparable amount of time. It was impossible to make a precise comparison because circumstances were different: in M a series of calculi was asked without interruptions, while in S the child had to switch from the game keyboard setting to the calculus one. Hence, we set S giving two seconds more to resolve the operations (7 seconds versus 5).

Another difference is that Memocalcolo had a prefixed number of calculi to solve (48).

4.3.2 Results

Children really liked “Stay alive”, although at the beginning they encountered some difficulties to understand its dynamic. Some of them had troubles coordinating keyboard and mouse, especially those not used to play videogames. At the end of the first session, all the children wanted to keep playing, proving their engagement level. The level of engagement was a major difference between the “Stay alive” (S) and the educational software (M). It was really difficult to keep children concentrated while using M and their faces were really serious and sometimes upset. The session lasted just 10 minutes but children often asked: “how long have we to do it?” Instead, during S testing their faces were concentrated but also happy and pleased and the session lasted 30 minutes.

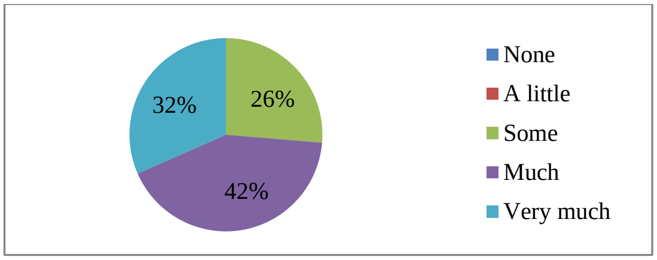

Figure 4: answers to: “did you like the game?”

These empirical considerations were confirmed by questionnaire answers (Figure 4). Some 76% of the children liked a lot the game and a total of 89% answered “yes” to the question: “Would you like to play again?”. None answered “no”. Figure 5 reports the comparison between the answers received for the same question with respect to M and S. 18 students out of 19 said that the game was more fun than the other games they usually use at school. At the question “Which game is more adapt for math learning?” 17 out of 18 selected “Stay alive”. To justify their choice, children wrote things like: “you have to do calculi to survive” or “it allows you to make calculi while playing”, and “it is not just math”. When asked about what they liked more, they mostly answered: “dodging bars”.

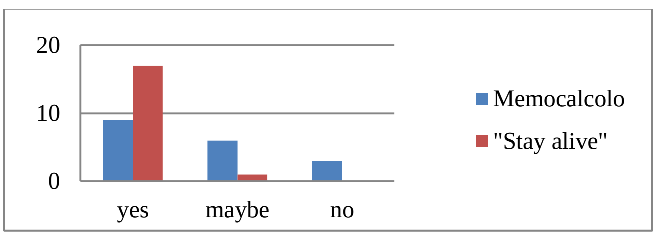

Figure 5: answers to: “would you like to play again?”

In the two sessions with “Stay alive”, children made an average of 55 calculi each, with peaks of 140 and lows of 20. From the Table 1 it is also possible to draw some conclusions about children attitudes: for example students who resolved calculi with high percentages of correctness but resorted rarely to math, probably are not very able to choose strategies because they could exploit in a better way their ability. Another interesting finding is that normally percentages of correct answers in S are equivalent to those in M but in some cases children answered much better in S (Table 1), confirming the token economy theory: they challenged more when they saw a personal return, rather than merely solving calculi. Furthermore children who most improved their performance are those with lower percentages in the pure math application. Child “C11” had math LD as it is possible to see from his 16% with Memocalcolo. Anyways, with the entertaining version he improved his percentage to 34% and above all he made 70 operations. However, he obtained just 102 points; it is evident that his logical difficulties were also correlated to low game abilities. This is an example of reasoning that is possible to do analyzing the collected data.

Table 1: comparison between Memocalcolo and “Stay alive”

	"Stay alive"			Memocalcolo	
child	calculi	correct	score	calculi	correct
C1	57	47%	416	48	31%
C2	93	78%	750	48	65%
C3	144	86%	707	48	81%
C4	39	64%	701	48	54%
C5	40	38%	232	48	27%
C6	83	48%	938	48	42%
C7	52	69%	350	48	42%
C8	41	32%	226	48	29%
C9	67	55%	386	48	38%
C10	134	72%	408	48	67%
C11	70	34%	103	48	16%
C12	30	43%	138	48	26%
C13	98	87%	536	48	73%
C14	33	52%	673	48	33%
C15	67	55%	450	48	40%
C16	20	40%	936	48	21%
C17	56	57%	415	48	50%
C18	27	37%	358	48	18%
	63,94	**56%**		**48**	**42%**

On the basis of the data analysis and observations we did, we can state that our goal of providing an engaging version of effective didactical methodology was reached. It is reasonably predictable that children could use this sort of games more willingly with respect to traditional software. As noticed by teachers, some usually passive and demotivated students, really transformed themselves while playing the games because their curiosity was stimulated, allowing them to have an effective learning activity. Another important consideration is about the compensation method. In the first test, the game was tuned on the basis of the trial phase, while in the second test all the children played with the same level of difficulty. In the first session there was a difference of 250 points between the higher (550) and the lower (300), while in the second it raised to 825 (938 versus 103). This result confirms the importance of that feature. With respect to children with LD they could enjoy the game autonomously with the rest of the class and we collected very encouraging feedback about their engagement level.

5. GAME 2: “ANIMALS’ BALLOON”

5.1 Educational goals

These are the specific goals for this game:

- To make exercises with arithmetical facts (numeric tables) to improve children fluency through association between figures (animals) and numbers.
- To enhance the children comprehension of numeric values and the meaning of “lesser than” and “greater than”.
- To strengthen the children association between symbols and numeric values.
- To experiment if cooperative inquiry techniques can be applicable with quite large groups of children.

5.2 Game description

This game was invented from scratch. The intuition was to find a subject which could be fun and easily understandable by children. This subject had to behave in such a way to help them in reasoning and exercising simply. "Animals' balloon" consists in a hot-air balloon floating in the middle of the screen and some animals flying or jumping on it. Every time the number of animals carried by the balloon changes, the game asks the total weight, showing a multiplication composed by the weight of the animal and the number of items. At the beginning of each level the balloon is empty and after few seconds the first animal arrives and goes on, the weight carried by the balloon changes and the latter starts to go down until the player types-in the correct result of the multiplication. The game repeats the same sequence for numbers from one to ten, starting from the lighter animal (an ant) and ending with the heaviest (an elephant).

Figure 6: the player has inserted a wrong answer, the balloon is going up and the calculus is re-asked. The balloon shows the result of the latest multiplication done.

If the player inserts a number higher than the correct one, an up arrow is shown for few seconds (Figure 6) and the balloon starts to rise proportionally to the entity of the error, simulating the real behavior of inflating hot air. If the balloon touches the ground it crashes and if it reaches the top of the screen it is swapped away by a strong wind. In both cases the game ends. So, the goal of the child is to provide correct results to keep the hot-air balloon in equilibrium. A score indicator is provided. It works in the following manner: at the beginning the game starts with 500 points. When the balloon is not in equilibrium the points decrease rapidly and stop when the equilibrium is restored. At the end of each level, the game resumes and shows all the statistics about correct answers and number of attempts. On the basis of them a bonus is calculated and added to the points. The higher is the score, the best is the performance in terms of precision and response time. Actually it is a complete indicator of the player's math ability. Furthermore the game stores all the sessions with data about level, accuracy, response time and score.

Also in this game a compensation method was adopted and it affected the balloon velocity, the decreasing speed of the score and the time animals take to reach the balloon.

5.3 Design process

Since the first intuition, the game appeared perfect for a cooperative inquiry activity with children involving them as design partners. We chose a different class from the previous two, with 16 eight years-old students. After the observation step there was a brainstorming session in which we presented the project and explained children their role, using a jargon adapt to talk with such young people. They proved to rapidly understand the aim of the meeting and early started to give suggestions and ideas, before we could finish to expose the whole activity. We decided to lead somehow the design process taking some decisions autonomously to avoid an ineffective and dispersive process, so our starting idea was shared with them asking to comment about the hot-air balloon: what it is and how it works. After that we proposed to include some animals and we decided together how to put them in relationship with the balloon. We decided to associate each animal to a number and then they had to choose which. Children were divided into three groups: one for lightweight animals, one for heavy animals and one for medium ones. Every child had to write three names of animals belonging to the category assigned to his/her group. We used this method to avoid biases and to allow also shy children to participate. Then every child red his/her list and we wrote everything on the blackboard dividing animals into three columns putting an "x" to count occurrences for each animal (Figure 7).

Figure 7: result of brainstorming activity with children

Then we ordered the most popular animals on the basis of their weight, discarding those not suitable for the purpose. For instance wolf and dog were too similar, while plankton was too difficult to draw and also barely recognizable by other children. All this reasoning was done with children to justify all the decisions we took. At the end, children were asked to choose three animals to draw by hand. A week later we collected all the drawings, chose the best ones, then we scanned, animated and imported them into the game. Finally, we presented the game to the class making a practical test session, and we had another brainstorming activity to elicit possible improvements as well as the name of the game. Also in this situation children participated a lot, and some nice names were proposed. Among others: "animals' balloon", or "indovina la tabellina" (in English "guess the table").

Finally children were asked whether they wanted to draw something else for the game and they accepted enthusiastically. So we started a practical session to draw the hot-air balloon and the background. Children were excited by the activity and they asked us to repeat a similar experience. They continued to tell ideas and suggestions to improve the game or to create new games, and sometimes one child improved the idea of another. They suggested how to make the balloon disappear or explode, or how to show the "game over" message at the end (i.e. an ant projecting the writing by its eyes). Obviously some ideas were not feasible but anyway children stimulated their fantasy.

5.4 Evaluation

5.4.1 Goals

One evaluation session was taken with the goals of assessing the playability of "Animals' balloon", measuring reactions, feelings, fun and engagement related to playing with something they really contributed to.

5.4.2 *Procedure*

We did not explain children anything about the functioning, to measure learnability and affordance of the game. The game session took more or less 20 minutes. At the beginning children complained about the speediness of the game, it was set-up really too fast for 8 years old people. Hence, the game was fixed and the test went ahead in a better way. During the game session children were very interested in discovering which drawings were selected, and they played in a quite ordered way. They also liked a lot the simple animations in the game (i.e. when the hot-air balloon was crashing on the floor deflating on a side). Finally, children were asked to compile a questionnaire.

5.4.3 *Results*

The empirical assessment of children's feelings was positive, even if the sensation was that the engagement level was a bit lesser than for the previous game. It could be due to the different nature of the two games: the first was a pure entertaining game adapted to learning purposes, while the second was designed from scratch to achieve such goals.

Usability and learnability of the game were good because few children needed help to understand how to play. However, they encountered some difficulties using the keyboard in a fast way to type-in the numbers, and it took a bit to overcome. Surprisingly, they were really interested in the answers percentage despite the presence of a score indicator, proving their awareness of the fact that they were actually learning and measuring their ability. They complained that the game was always restarting from the beginning, without the possibility to choose the level. It is surely a possible improvement. Each child made an average of 55 calculi, with a peak of 132 (in this case the child reached the table of 8, while on average his class-mates stopped at the 3 table).

From an analytical point of view, all the children except one liked "Animal's balloon" much or very much (respectively 31% and 63%). All but one answered "yes" to the question "would you like to play again?". Children were also asked where they would like to play. The question had free choices but they all wrote either school (79%) or home (21%). We decided to leave it open to give children the possibility to eventually write unexpected answers but it did not happen. One of the meaningful questions was: "I felt like...". 71% answered "playing" rather than "doing homework" (Figure 8). This outcome confirms our attempt to create games, to exploit motivational factors like competitiveness and engagement.

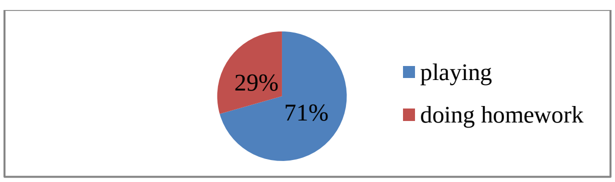

Figure 6: answers to: "I felt like…"

Among things children liked the most there are animals getting on the balloon, and to win/pass the level, while among what they less liked we can find: to loose, speed and restarting from the beginning. At the question: "Did you enjoy participating in the project?", they confirmed our feeling answering almost everybody "very much" (69%) or "much" (25%), while only 6% answered "some".

6. GAME 3: "CAT & MOUSE"

6.1 Educational goals

This game had a different goal: to provide a tool for educators or parents to motivate children to make math exercises while playing with them. It is especially thought for children with concentration difficulties such as hyperactivity.

6.2 Game description

"Cat & mouse" is really simple: there is a field on which a cat and a mouse can move (Figure 9). The cat (played by the adult) has to catch the mouse (played by the child). When the cat touches the mouse, the latter has to solve a calculus within a certain time, if he/she does correctly nothing happens and he/she has some seconds to run away, otherwise he/she loses one life. There are some obstacles to dodge and objects to catch that can make the characters go faster or slower. Points that can be earned when coins are collected or calculi are resolved. After two minutes the game switches to the next level, increasing the speed of the cat and the difficulty of the calculi. Also this game is provided with the calibration method that in this case is used to choose the set of calculi and the available response time.

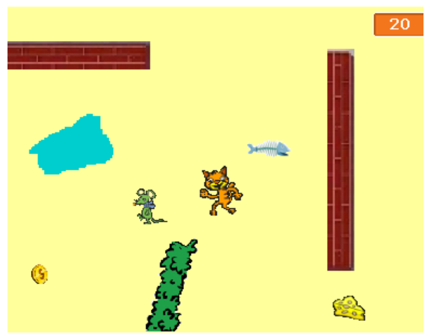

Figure 7: a "Cat & mouse" screenshot

6.3 Evaluation

6.3.1 *Goals*

The main goal of this evaluation was to test the effectiveness and applicability of the approach based on a two-player game.

6.3.2 *Procedure*

"Cat & mouse" was tested by five educators during the personal training with six children affected by LD, aged between 7 and 11. They had some game sessions and took notes about usability, practical issues, results obtained by the children and usefulness of the tool. Educators assessed the game during their standard activity with students; hence we could not be present to preserve the usual conditions. They tried to exploit the game to make math exercises and finally answered a questionnaire to report their impressions. The children had the following conditions associated to LD: Down syndrome, mixed specific developmental disorder, mixed disorder of scholastic skills, attention deficit hyperactivity disorder and mixed disorder of conduct and emotions.

6.3.3 *Results*

The empirical evaluation had positive results: children really enjoyed the game and in some cases it appeared more efficient than classical methods. All the involved adults evaluated the game as very useful for their activity and able to facilitate their relationship with children. They also stated that pupils surely could benefit from such a game. Some children looked forward to the moment to play and wanted to know the link to be able to play at home with their familiars.

The game was suitable and had a good level of involvement for all the children, except for one affected by Down syndrome because he had too difficulties to use the keyboard. "Cat & mouse" was particularly effective for a child with autism-like symptoms because it represented a sort of bridge to interact, overcoming communication barriers that children with this disease have. Another point of strength was motivational factors like the game itself and the challenge between the adult and the child that helped students to keep their concentration, especially for those affected by hyperactivity and conduct disorders. Personal trainers normally have hard times working with with such children using traditional methods because of the continuous distractions and the lack of stimuli. As a result, educators defined the suitability of the game as "outstanding".

From an analytical point of view, it is difficult to draw objective conclusions because it was impossible to have a longitudinal assessment. Anyway, since the adopted educational methodology has a proven effectiveness and the game shown to be suitable, it should gain good results especially in the long term. It could be a future possible evaluation.

7. CONCLUSIONS

Learning difficulties can really affect the life of a person, conditioning and narrowing his/her future chances and choices. There are a lot of methodologies and tools to mitigate LD impact but there is still a lot to do. The results of this activity can be a stimulus for future researchers to base their work on a different approach. In fact, we figured out that finding engaging scenarios to apply proved methodologies could be the key for their effectiveness. The prototypes we developed demonstrated that motivational factors included in a game can really lead children to do math exercises avoiding discriminatory and frustrating circumstances. They can represent a useful tool for educators and parents to help them in their difficult challenge in supporting disadvantaged children in their learning processes. We can also confirm the validity of the participatory design pattern and the importance of specific techniques to collaborate with children.

On the basis of the experience undertaken, we can list some suggestions for those who are interested in conducting a similar activity.

- Do not underestimate children and their contribution: they understand more than we can expect and are often surprising.
- Do not limit a priori their level of involvement in the design process: children force us to keep questioning.
- Be simple in speaking, thinking and designing.
- Always appreciate ideas: children need their ideas to be heard and given importance, it is really crucial for their self-esteem and makes participatory design successful.
- Create bridges: children and adults belong to different worlds, find ways to help them communicate; drawing is an important one.
- Avoid discrimination: children will carry "labels" for all their lives, avoid creating them when you design something.

8. ACKNOWLEDGMENTS

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