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Virtual Worlds for Serious Applications (VS-GAMES'12)

Design criteria for educational tools to overcome mathematics learning difficulties

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Abstract

ICT educational tools can play an essential role in the cognitive development and inclusion of disabled people. In this paper, starting from the mathematics learning difficulties of motor-impaired people with cerebral palsy, we argue that in this field specific educational tools are propaedeutic to a more informal learning approach based on serious games. Then, we describe some design criteria (concerning the learning strategies, the graphical appearance of the entities involved, and the customization of the activities) and some educational tools we have developed accordingly.

Keywords: educational technologies; serious games; mathematical learning; disability; e-inclusion; cognitive development.

1. Introduction

In education, as well as in almost all the human activities, the increasing adoption of ICT has created the conditions for significant improvements in the ability to acquire, produce and exchange information. This is of particular importance because better education and fluency in ICT meets the objectives of e-inclusion, i.e., global accessibility to ICT and better people integration through ICT [1]. Although this is important for all learners, for disabled people ICT educational tools can be in many cases essential to overcome motor, perceptual or cognitive difficulties that prevent or at least make difficult their inclusion in the society. More specifically, the cognitive development of disabled children is very often encumbered and delayed by disability as, for example, it is the case with motor-impaired children by cerebral palsy. In fact, their cognitive development is slowed down or prevented, both by the neurological damage suffered and by the fact that their motor disabilities make much more difficult to live the experiences that normally concur to the development of

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the cognitive abilities in non-disabled children [2]. Therefore, ICT educational tools can play an essential role for the cognitive development of motor-impaired children, both the logical-linguistic and logical-mathematical fields, provided that they implement the methods, plans and timelines for learning which have been chosen for each student [3].

On the other hand, in addition to the traditional educational tools, during the last decades there has been a growing interest in implementing more informal learning approaches. In this context, a major role is played by games which are specifically designed or used to yield some predefined learning outcomes. In particular, during the last years great interest has been focused on Games-Based Learning and Serious Games (SG), typically denoting games that have been studied and developed having in mind the improvement of knowledge or skills by the users rather than pure entertainment and fun, although having fun during game playing is a major feature (the two terms are also used with the same meaning, although the application target of SGs is broader and not restricted to education) [4].

However, the elusiveness of the term serious game has suggested to propose broader definitions. For example, in [5] it has been argued that there is a continuum from games with traditional gaming activities and characteristics (such as challenge, play, fun, etc.) to games with minimal gaming characteristics and whose main purpose is to provide experience and emotion to convey meaning. An even broader definition is argued in [6]: *All games are serious*, so that the popular online virtual world *Second Life* and life simulation games of the family *The Sims* can be legitimately considered genuine serious games provided that their use is not limited to pure entertainment. The use of SGs is not restricted to programs running on stand-alone computers but span other application fields, such as online games [7], interactive TV [8], or Wii video game console [9]. Moreover, since the SGs need the definition of suitable and customized virtual world, methodologies and tools are needed to make easier their production by domain-experts [10-11]. Another important issue concerns the assessment methodology, which in turn is often based on some psychological theory [12].

More specifically concerning the use of SGs for disability, many research has been done in this field, for example [13-16], and many research projects have been developed, e.g. [17-18]. However, as it will be explained later, in many cases the use of SGs be preceded by the use of educational tools characterized by simpler graphics, without animation and VWs.

This educational tools must be implemented meeting specific requirements concerning the learning strategy to be followed, the graphical appearance of the entities involved, and the flexibility in providing a suitable and easy customization of the exercises and of their parameters. In this field, starting from the direct experience gained with our daughter M. who is affected by cerebral palsy, our research has concerned the study of methodologies and educational tools for the cognitive development of people with learning difficulties in the logical-linguistic and logical-mathematical fields. In particular, in this paper we will focus on mathematics learning difficulties, and describe and discuss some design criteria which are applicable to the implementation of educational tools to overcome these difficulties.

2. Motivation and background

Although many cognitive difficulties suffered by people with cerebral palsy are directly imputable to the extension of the lesions in the cerebral areas that are appointed to the high-level cognitive functions (e.g., the language), there are also cognitive problems due to the limitations imposed by the motor impairment. This is because, during the first years of life, the ability to perform motor actions and objects manipulation in the surrounding world, and the ability to pick up information from the environment by exploring and modifying are highly instrumental in the formation of the knowledge [19-20]. So, the influence of the limitations of the motor experiences to learning must be verified on a case by case basis, taking into account that during the first year and half of life the mental and the motor activities are hardly dissociable [21]. Moreover, the motor impairment makes difficult to perform essential operations such as typing, so that other approaches, such as multi-letter keyboards or application of word prediction techniques have been proposed [22-24].

In particular, in the mathematical field the difficulties can be operational or cognitive. Concerning the latter, there are the difficulties in acquiring the different meanings of the numbers and of the four basic operations. Actually, already starting from the first learning acquisitions, disabled children have a major difficulty in learning the concept of number in its different meanings (ordinal, cardinal, measure, value, and so on), whereas 5 year old children are typically able to read and write numbers and to compare them also using complex strategies, even if full maturity in the autonomous elaboration of the numerical information grows gradually, together with the mathematical abilities [25].

In fact, together with the intrinsic limitations due to the cerebral damage, motor-impaired children have very limited experiences of mathematical modeling built on motor actions, so that the base for learning the concept of number in its different meanings is largely insufficient. Other difficulties can be often due to the educational lines adopted in the school. For example, when the introduction to numbers is based uniquely on sets (and then on the cardinal aspect), this can impede the acquisition of the other meanings of numbers by the disabled person. This is because different cerebral regions are involved in the treatment of the different meanings of numbers, so that they cannot be directly deduced the one from the other [26].

Therefore, the design of the ICT educational tools must be inserted within the framework of an approach to the different meanings of the numbers and of the elementary operations [27]. Moreover, the educational activities and the related ICT implementations must be closely related to fields of experience that be meaningful of concrete situations of the real world [28-30]. In fact, the immersion in a real field of experience makes easier to build a suitable solving strategy for a specific proposed problem, by recalling known schemes of behavior, with a positive effect to the cognitive development.

For example, the *Calendar* is a natural field of experience to consolidate the ordinal meaning of the numbers [31], for the use of a real calendar makes it possible to build the ordinal meaning of the number in tight connection with the ordering of the days, starting from counting numbers. Other natural and suitable fields of experience concern *Money* (with coins and banknotes), *Clock* (with a digital clock), *Temperature* (with a thermometer). The implementation of methodologies linked to real fields of experience has the additional advantage to avoid rote learning, as is the case for many educational tools which basically ask the person to simply repeat specific actions triggered by the recognition of specific situations.

The result is that, in presence of even minimal changes of the environment conditions, the disabled is not able to manage the new situation because the mechanical execution of operations that are not linked to real meanings has not helped the person to build a better inner capability to understand and react with the environment. Anyway, it is necessary to always keep in mind that each case has its own specificities, and that typically very long times (several years) may be needed to achieve significant results.

3. From educational tools to serious games

As already stated, the fields of experience (as well as the educational tools that implement them) use concrete situations which are known and natural to the people and help to manage them more independently. In fact, starting from a low level of knowledge in a given situation, it is possible to both reach more complex achievements in the same situation, and extend the knowledge to more complex situations in the same field of experience. For example, within the field of experience *Money*, one can begins with simple situations, such as: to know and recognize the different coins and banknotes and their associated values, to compose prices, to buy with exact payments (i.e., without any change), to find how much money is left in the wallet after the payment.

All these activities have an intrinsic usefulness but they are also very important to achieve the knowledge of the different meanings of numbers and of the arithmetic operations. A good fluency in these basic activities makes it possible to act in more complex situations, such as to buy and sell with change and discount or to find the incomes and the gains, up to very complex situations, such as to understand and manage bank operations. In other words, the main learning objective is that to allow people to act, giving correct solutions, in situations and activities that are more and more complex. In this context, it is natural that, beside the use of educational tools which implement the desired field of experience within a significant learning framework, the learning activities be integrated with game-based learning and serious games, where the desired knowledge acquisition is conveyed in a less formal and hidden way, by the unconstrained execution of a game activity in a graphical virtual world.

Although SGs have been developed to support learning of basic mathematical concepts in cognitive disability, for example [32], many cognitive-impaired people could not be able to profitably use SGs in the mathematical field, if this require some basic knowledge and cognitive skill to use the SG with awareness and not mechanically. In this case, it is strictly necessary that the use of SGs be preceded by the use of educational tools implementing a specific and visible learning framework and characterized by simpler graphics, without animation and VWs.

This has been the case of the well-known life simulation game *The Sims 3* , whose Wii version has been used intensively by our daughter M. since its release in 2009. Indeed the game is available in several other platforms, including PS3, but M. (and presumably also people with significant motor and perceptive impairments) found it very difficult to use, because of the small font of the text and of the difficulty to use the joystick. The usefulness of the game lies in the fact that it can be played at different levels of complexity concerning the required knowledge and skills, and that the conscious use of the game can improve both knowledge and skills; this, in turn, makes it possible to switch to higher levels of complexity of the game.

For example, M. has really understood what means to pay domestic bills after playing *The Sims* about, in real situations belonging to Money. But, she herself has stated that this had happened only after the intensive use of the educational tools in the field of experience *Money*, on coins management first and on buying/selling after. Instead, before this training activity, she played the same situations about home management in *The Sims* game, but in a purely mechanically way, without having really understood the meaning of her activities and without much fun, whereas she had acquired the real awareness of what she was doing after the use of the educational tools, which had reinforced in her the numerical meanings related to using coins and buying/selling.

Another example is that, before the use of our educational tools, while playing *The Sims* M. was not able to understand why she was unable to buy objects. On the contrary, after using it after the same training with the educational tools, she realized by herself that the reason for this inability was that she did not have enough money in her wallet. Then, we can argue that our educational tools have played a fundamental and propaedeutic role for effectively using educational SGs on situations belonging to the same field of experience. Moreover, the conscious use of the game has made playing it more engaging and enjoyable.

It is worth noting that these two examples have been suggested by M. herself. This is another significant fact, because we can argue that the propaedeutic use of our educational tools, followed by the conscious use of a SG in the same field of experience, has produced not only an improvement of her specific knowledge in the field of experience *Money* but also a significant improvement of her metacognitive skills.

4. Design criteria

In this section we will describe and discuss some basic design principles and guidelines for the implementation of educational tools targeted to overcome mathematics learning difficulties in people with cerebral palsy. According to the direct experience gained with our daughter M., we can argue that the educational tools to be implemented should meet some general requirements, and other requirements concerning the implementation of the learning strategy and the customization of the proposed exercises.

4.1. General

In implementing the mathematical educational tools that we are considering it should always be bore in mind both what is the purpose of the tools and who are the target users.

1. The purpose is to support learning of the basic mathematics concepts by using a field of experience belonging to the real world, and performing operations (such as buying, selling, changing money, reading and surfing the calendar, etc.) which are useful in the real life.

2. Although also usable by other users, the educational tools we are considering must be usable by non severely motor-impaired people. For this reason, it should be avoided the need of actions that are almost or totally impossible or very difficult for motor-impaired users, such as multi-key actions on the keyboard or complex mouse actions involving both text selection and dragging. On the other hand, it would not be convenient to restrict actions to single-key keyboard gestures, because of the high affordance [33] intrinsic in the use of mouse to select buttons and move objects (such as coins), which makes easier the work for people with moderate motor-impairment. As a consequence , the above restriction or more severe ones (such as selection by scanning) should be considered only for tools that are specifically targeted to the most severe cases of disability.

3. As already stated, the educational tools should provide an adequate immersion in real fields of experience that are related to the desired mathematical achievements and are as much as possible similar to real situations that the person will find in the real life. Since some fields of experience involve different possible real situations, it may be convenient to implement different tools for the different situations, rather than to build a single program to meet all of them. In fact, the different real situations can require very different arrangement of the objects on the screen and actions to be performed, so that their inclusion as different options of the same program does not have a strict functional justification. Instead, the disabled person will find much more intuitive to associate each given specific real situation with a specific program name. Obviously, this does not impede that a set of educational tools be included in a unified execution environment, by implementing a graphical menu interface which provides the access to the different educational tools and, possibly, to a suitable set of serious games the same tools are propaedeutic to.

4. Concerning the appearance of the tools on the computer screen, it is convenient to adopt a full-screen visualization. In fact, in this way the whole screen is available to display objects, and to select and move them, making easier the operations to be performed by people with reduced motor capabilities. Moreover, with a full-screen visualization, the user attention is completely focused on the execution of the required task, not being distracted by the visualization on the computer screen of other windows, and he/she has not to worry about resizing, moving or iconifying the window of the tool.

4.2. Implementation of the learning strategies

The selected fields of experience, involving significant operations in the real world, are: *Calendar*, *Money*, *Temperature* and *Clock*.

1. Although each field of experience has its peculiarities, if the implementation concerns a set of programs the overall choices about the layout of the pages should be the same or, at least, similar. This characteristic is very useful because in this way the person minimizes the cognitive load for both learning how to use the program and to switch among different programs. In particular the different programs should have, by default, the same set of background and foreground colors for the pages and for the principal types of objects. Moreover, all the programs should have the same general page navigation structure, consisting in: 1) an entry page with the title, parameters (see below), an *Exit* button (*"Esci"*), and a few navigation buttons, each one associated to a specific subtask of the tool, 2) *n* subtask pages, one for each navigation button in 1, and each one containing, together with all the objects needed to perform the subtask, three navigation buttons for the

Entry page (*"Pagina Iniziale"*), *New exercise* (*"Nuovo Esercizio"*), and *Exit* (*"Esci"*), put in the lower zone of the screen. Figs. 1-4 display, on the right, some subtask pages for 4 programs, one for each field of experience (on the left there is the English translation for each page). Fig. 1 shows one of the screen page for the program *Il Calendario* (*The Calendar*).

Fig. 1. Example of subtask page (field of experience *Calendar*)

2. Concerning the specification of the exercises to be proposed, it is essential that the content of each exercise and the sequence of the exercises be strictly non deterministic. This to avoid that the same sequence of always identical exercises be cyclically repeated (when, for example, buying a T-shirt at 15.49 €. is always followed by buying a pair of trainers at 24.30 €), which can be perceived as highly boring and discouraging by the user. This can be obtained by properly applying random number generation to randomly span the range of the possible problems.

Fig. 2 displays a screen page of the program *Attenti alla Spesa!* (*Watch your Shopping!*) implemented for the field of experience *Money*, and concerning the shopping activity.

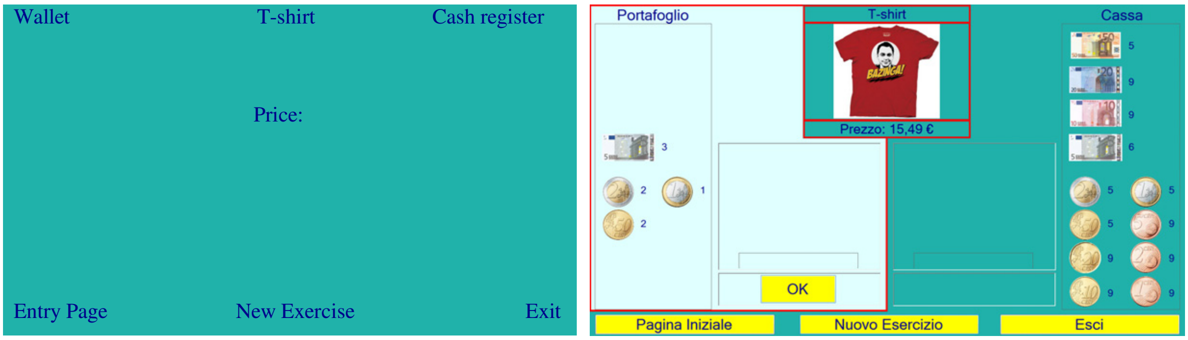

Fig. 2. Example of subtask page (field of experience *Money*)

Fig. 3 shows a screen page of the program *Le Temperature* (*The Temperatures*) with the random generation of two temperature that must be compared after having set them on the two graduated thermometers. Finally Fig. 4 displays one of the screen pages of the program *L'Orologio Digitale* (*The Digital Clock*) with the random generation of two times, the current one and that of a future event; the user is asked to answer to the question "how much longer is it?" by reaching the final time adding minutes to the time.

Fig. 3. Example of subtask page (field of experience *Temperature*)

Fig. 4. Example of subtask page (field of experience *Clock*)

4.3. Customization

The possibility to customize in a flexible way the functionality is a significant feature for any tool involving some form of human-computer interaction, but it is of major importance for educational tools targeted to disabled users. In fact, the presentation of the same activity, e.g. selling proposed items, must be carefully tuned according to actual learning objective and to the level of expertise already reached by the person. The main ways to do this are to give the teacher the possibility to set some parameters and to implement the tool as an open environment.

1. The tool should allow the teacher to directly set the main parameters which modify the functionality of the operation according to the type of learning required and to the level of difficulty of the exercise. To make more intuitive and easier, both for the student and for the teacher, the operations of reading and setting the parameters values, we suggest not to use the classical hidden menus on top of the window, but to put the related objects in the entry page of the tool. For example, Fig. 5 it shows the entry page of the program *Attenti alla Spesa!* (*Watch your Shopping!*) implemented for the field of experience *Money*, and concerning the shopping activity. The displayed parameters, which are typical for this field of experience, concern: 1. *the coins and banknotes that are available in the "wallet" of the buyer*, 2. *the use or not of Euro cents for the "wallet" and for the prices*, 3. *the max number of pieces of the same coin/banknote that can be generated*, 4. *the min and max costs of the items actually proposed*. The values of the parameters are read (and updated at the end of the execution) in a textual configuration file allocated in the AppData folder of the user, together with the specification of all the colors that are used to display the pages of the program (so that the colors can be

possibly modified). To obtain a high affordance for the use of the buttons, a vivid color (default is yellow) is associated to the set condition.

Fig. 5. Example of entry page (field of experience *Money*)

2. In a field of experience such as *Money*, which contains activities of buying and selling items, it is not convenient to implement a closed environment, i.e. one in which the number of items and their prices are prefixed and embedded in the executable. In fact, in this way the number of items, their images, and their prices could not be updated. Moreover, it would not be possible to increase the number of items to prevent that a single exercise comes up again too often, especially in presence of a constrained set of parameters (for example concerning the price range of the items to be proposed). For this reason we suggest that all the data concerning the items to be proposed in the exercises be provided in a folder containing all the image files and a textual file that, for each product, specifies its name, image file and price.

4.4. Programs details

In addition to the already cited programs (namely *Il Calendario* (*The Calendar*), *Attenti alla Spesa!* (*Watch your Shopping!*), *Le Temperature* (*The Temperatures*), and *L'Orologio Digitale* (*The Digital Clock*), other five programs compose the set of educational tools we have developed according to the design criteria outlined above, namely *L' Abaco delle Monete* (*The Coin Abacus*), *Attenti al Cambio!* (*Watch the Exchange!*) , *Attenti al Resto!* (*Watch the Change!*), *Attenti allo Sconto!* (*Watch the Discount!*) , *Il Cambiamonete* (*The Coin Exchanger*), all five belonging to the field of experience *Money*.

All the programs have been developed with Visual C# and have been installed and tested on Windows XP and Windows 7 platforms equipped with .NET Framework 4. As already stated, all the programs are characterized by the same graphical choices, according to the proposed guidelines.

Moreover, although the actual customization of the parameters is provided through the use of a configuration file and, for buying/selling programs, a folder that contains all information about the items, all the programs can use default values if the customization files are missing or corrupted.

The educational programs that have been developed are freeware for personal and non-commercial use only; the self-installing executables can be freely downloaded, and distributed under the same terms, from the website *http://www.eastlab.dibe.unige.it/*. Possible future developments could concern the following points.

Multilingual implementation. All the programs but one, in which the multilingual feature has already been experimentally tested (*Il Calendario*), are presently implemented in Italian language. In the multilingual version, each program could make it possible to freely select, in the configuration file, one of the languages whose texts are provided in a language database that is not embedded in the program and is easily modifiable and updatable.

Awarding activities. According to the spirit of the games, the program could assign a score to the user and reward accordingly the successes in executing the proposed activities. Moreover, automatic switch to higher complexity levels could be proposed after reaching some specified score values; for example, in the field of experience *Money* we could have the transition from activities with prices without cents to activities with full prices, or from activities with absolute discount to activities with percentage discount. Now, these transitions are set manually by changing the parameters in the entry page.

SG implementation. We have argued that our educational tools can play a fundamental and propaedeutic role for effectively using educational SGs in situations belonging to the same field of experience. Therefore, the environment of an educational tool could be extended with the direct implementation within the tool of a suitable SG level working on the same activity (for example buying) with graphical animation.

5. Conclusions

ICT educational tools can play an essential role for the acquisition of basic logic-mathematical concepts by motor-impaired users by implementing the operational steps suggested by a suitable learning methodology. This provided that the proposed activities concern the involvement in a real and significant field of experience. As we have described, the educational tools must meet specific requirements concerning the learning strategy, the graphical appearance of the objects involved, and the flexibility in providing a suitable and easy customization of the exercises and of their parameters.

In this context, some basic design principles and guidelines have been described and discussed, both general and concerning the implementation of the learning strategy and the customization of the proposed exercises. The described design criteria have been applied in the implementation of a set of educational tools providing operational activities in the fields of experience *Money*, *Calendar*, *Clock* and *Temperature*. The programs, running on Windows XP and Windows 7 platforms equipped with .NET Framework 4, are freeware for personal and non-commercial use only, and can be freely downloaded and distributed under the same terms.

The adopted learning methodology and the described educational tools, together with several other programs that have been implemented during the last years [2,27], have been tested in intensive and continuing way with our daughter M. Significant results have been obtained both for the enhancement of her cognitive and metacognitive skills and for the acquisition of new theoretical and practical knowledge [34].

In particular, it has increased the ability to link thought to reality, and the thought activity has become able to better take into account the constraints put by the external world and to handle more and more complex situations. Similarly, significant results have been obtained in the management of the memory, both for reminding actions and facts of the past, and for fixing in the memory new relevant facts. Another significant result we have observed is that the propaedeutic use of our educational tools, followed by the conscious use of a SG in the same field of experience *Money*, has produced both an improvement of her specific knowledge field of experience and a significant improvement of her metacognitive skills.

Recently, we have started an experimentation to test both the methodology and the tools with some children frequenting primary or middle lower schools, with significant learning difficulties, but not due to motor-impairment. Although the disabilities are quite different, we have found quite similar learning difficulties. So it will be very interesting to verify if the proposed learning methodology and the use of our set of educational tools can be similarly useful also for these so different cases.

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