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Educational Digital Recycling: Design of Videogame Based on "Inca Abacus"

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1. Introduction

The use of multimedia applications in schools is quite common. However, according to Alfonso Gutiérrez (2003: 42), these are often attributed educational advantages, which perhaps they do not have and just like that, it is assumed it favors learning. From a creative design perspective, how can we make educational multimedia resources really contribute to an effective teaching-learning process? We believe a key aspect has to do with the possibility of digitally recreating or recycling some traditional teaching materials that have proven to be effective teaching tools. Among them, we find the so-called "Inca abacus" known in Peru and other countries of the region as "*yupana*".

Fig. 1. Drawing made by chronicler Felipe Guamán Poma

On the lower left corner of a 16th century drawing (figure 1), made by chronicler Felipe Guamán Poma, there is a sketch of a *yupana* next to the *quipu*; therefore, it is believed they were complementary calculation tools. The term *yupana* comes from the Quechua word "*yupay*" that means "to count". Originally, it consisted of a clay or stone tablet with several columns and boxes with small grooves for placing corn kernels. Researchers have not reached an agreement on how it was used in the olden days; however, for its use in schools, the interpretation made by the engineer William Burns has been chosen, which is based on the decimal system (Bousany, 2008: 18). The tablet has been turned into a horizontal position, where each column has the value of a multiple of ten and each circle has the value of one multiplied by the value in its column. The upper boxes are used as a memory or for exchange and underneath, there are ten circles, grouped in two, three and five units to facilitate counting (figure 2).

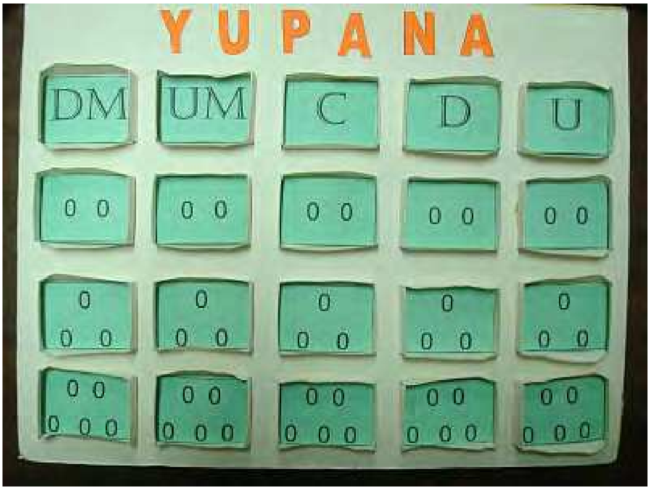

Fig. 2. Representation of the decimal system in the *yupana*

In the eighties, the *yupana* was promoted as a teaching aid for the first elementary grades by the Peruvian teacher Martha Villavicencio; since then, some schools make use of traditional *yupanas* made from wood, cardboard or Styrofoam and numbers are represented with buttons or seeds (figure 3).

There are research and testimonies certifying the educational capacity of the *yupana* in facilitating the understanding of the positional value of numbers in the decimal system and the execution of immediate arithmetic calculations (Vargas & López, 2000: 75). It is stated this is an educational and historic tool "[…] that helps students understand certain mathematical algorithms that are many times applied in a mechanical way without knowing the logical part." (Torres, 2009). Taking into account the importance of mathematics in basic education and the difficulties and resistance generated in its learning, we decided to investigate the feasibility to digitally recycle the *yupana* with the purpose of strengthening its qualities and make it more attractive for digital natives. For this interdisciplinary work, we counted with the advisory services of a specialist in mathematics education, David Palomino, and of a multimedia application designer, David Chura.

Fig. 3. Use of the traditional *yupana* in school

2. Educational digital recycling

2.1 Traditional learning and digital recycling

The origin and sense of the term "apprentice" is interesting. Professor Mariano Aral, a specialist in Spanish lexis, explains it in the following way:

The complement of an apprentice is basically the teacher, that is, the traditional teacher (one who masters a trade). […] What was characteristic of all skills in relation to their respective apprentices was that it made them work (apprentices did not just learn, they learned by doing). […] When passing from a traditional society to an industrial one, it was discovered that the industry was not the best place for apprentices, they went straight to production and they had to know already and take a productive space in the company. Therefore, learning had to be achieved in school and not in the industry. […] It was a total revolution. Instead of masters they gave them teachers. Instead of providing them with machines, tools and working material, they gave them paper and pencils, and books and blackboards. Instead of practice, they were given explanations and more explanations and instead of turning them into apprentices, they remained as students. (Aral, 1999).

This interesting text from Mariano Aral expresses certain nostalgia for traditional education based on practical learning with specific materials. Other authors go beyond and link traditional culture with the digital era. Juan Freire –in agreement with the expert in innovation Charles Leadbeater- believes that the industrial society was an anomaly and that the digital era is not a revolution but the recovery of ways to work, participate and share that we believed had been forgotten. The industrial revolution meant an increase in efficiency in detriment of the pleasure of learning by doing, of talking with those around us and of making collective decisions without external authorities. With the arrival of the digital era, Freire once again says, "[…] spectators become digital artisans, the profane knowledge is reappraised, and knowledge is shared once more, it is copied and remixed in a creative virtuous cycle." (Freire, 2006). A way of conceptually explaining this phenomenon is through McLuhan's laws on the media. According to Piscitelli's review (2005: 121-122), these laws state that each technology expands or amplifies a skill, by doing so, it outdates an older means and at the same time, it recovers something that was previously obsolete; and if it expands too much, it turns into something new. As we can see, the fact that a new technology rescues previous forms or means is a central part of the proposal.

We can define educational digital recycling as a way of recovering and transforming traditional learning materials to introduce them into a new life cycle more in tune with the new generations. Here, the sense of transformation involved in this process is worth pointing out. Today, there are virtual educational resources but many of them are limited to copying or simulating materials from the real world. In order to analyze this point, I would like to tell you a personal anecdote.

When my oldest son was three years old, he used to play with a Disney multimedia to learn to paint. The interactive design of the interface showed a brush, drawings for coloring, paint jars with basic colors and a pallet for mixing colors. The task or challenge consisted in painting the drawings with the same colors as in some reference pictures. My son always had a hard time obtaining green by mixing the yellow and blue paints and if he did, it was just by chance. One day, we were walking down the street and he needed to go to the bathroom. So, we went into a public restroom where they had just finished cleaning and the toilet water was blue from the disinfectant. When he started urinating, my son was surprised to see how the blue water changed color. I took the opportunity to explain that by mixing yellow with blue you get green and he never forgot this lesson. Moreover, he was capable of transferring what he had learned. Once he poured a yellow-colored soft drink into a blue glass and when he saw the glass turn green, he immediately remembered the restroom experience.

Some experiential learning processes are impossible to reproduce virtually. Therefore, the first condition for educational digital recycling is to start from a resource or material that can be subject to transformation and be enriched with digital technology. On the other hand, if we compare the Disney multimedia with the bathroom experience, we can discover several differences. The multimedia interface shows an environment that simulates an artistic surrounding, appropriate for someone who is getting ready to paint with a set of colors. On the other hand, a public restroom is an unusual and rather inappropriate place for learning to paint. But maybe, just because of that, it is capable of generating greater surprise and interest. Neuroscience has shown that emotion favors learning. According to John Medina (2010: 94-95), when the brain detects an event with an emotional content, it releases dopamine, a neurotransmitter that aids memory and information processing. It is like if the brain placed a chemical post-it note with the statement: "¡Remember this!" so the information can be processed more thoroughly. Another basic difference between multimedia and the restroom experience is in relation to the way the green color appeared. In the Disney material, when the brush dipped in the blue paint touches the yellow paint in the palette, the green color appears automatically, as if by magic. In the toilet bowl, the effect is in real time, progressive, which fixes the attention on the mixture of colors and increases curiosity.

As we said before, many educational virtual resources simulate materials from the real world. For example, there are several digital applications of the Chinese abacus on the web (figure 4) that reproduce its physical characteristics with some interactive functions.

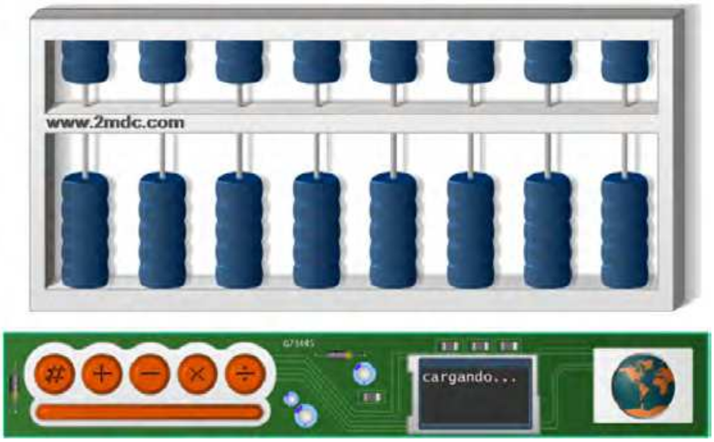

Fig. 4. Digital version of the Chinese abacus

On the other hand, there are recent projects in Bolivia (Murillo, 2010) and Colombia (I.E. Once de Noviembre, 2010) of digital or virtual *yupanas* (figure 5). In all of these cases, they are multimedia resources that use digital technology but not the digital "culture"; that is, they are applications that do not take advantage of communication formats or styles that have developed around the new mediums.

Fig. 5. Examples of virtual *yupanas*

In our case, we decided to creatively transform the *yupana* into a space videogame, which we called "Yupi 10" (figure 6). We only included four columns in the prototype (up to thousands) and we aligned all the circles vertically with the purpose of simplifying the design and facilitating its use, not only in PCs, but in mobile phones and tablets as well. The game was developed with Adobe Flash. In the case of platforms or devices that do not support Adobe Flash Player, we would have to develop versions of the game with other tools, such as Objective-C, Java or HTML5.

Fig. 6. Main screen of the Yupi 10 videogame

2.2 Yupi 10 basic rules

Educational videogames can be included in a category called "serious games." This concept usually includes games that have a purpose other than simple entertainment and whose application field is quite varied: ranging from military training to education in health and going through business training or artistic education. (Susi et al., 2007).

In relation to the educational potential of electronic games, it has been criticized (Buckingham, 2008: 173) that a large part of these packages are focused on the practice of out-of-context skills or factual contents of subjects, where the user just has to answer questions choosing from various options; more than teaching, the intention seems to be that of assessing skills or pre-acquired knowledge. Tejeiro & Pelegrina (2008: 135) quote studies, which alert of the possibility that educational videogames favor experiential cognition, based on reactions to successive events, but not reflexive cognition, which would enable applying what has been learned to other areas. It is stated that the context of the game causes higher motivation levels; however, this seems to interfere with reflexive cognition, so students are able to transfer their understanding of game principles to other games but not to extract the rules on which they are based. It has also been observed that without guidance from a teacher, participants in an educational videogame focus on the competitive nature of the game and not on following up of their own understanding. This has been interpreted in reference to Vygotsky's concept of the zone of proximal development, according to which individuals can pass a learning level when they are helped by a more competent person. Other authors have indicated that videogames can be useful for "[…] teaching external abstractions such as mathematics or physics, but they have limitations when representing introspection or philosophy." (Zagalo, 2010: 65).

In reality, all these observations do not invalidate the use of electronic games in school; they just warn us about the conditions a videogame should meet to really be educational. We believe that the main condition has to do with the basic rules of the game, understood not so much as the playing instructions but rather as structural principles of the creative design. For example, a videogame in the form of a labyrinth would be appropriate to learn notions of laterality and spatial orientation (left / right, up / down). However, there are cases in which the labyrinth is only a recreational pretext to "catch" numbers, letters, animals or any object related to an allegedly educational subject. It would seem that first the format is decided upon and then content is sought for it. But this problem is not exclusive of the digital setting, in the real world there are tabletop games with a board and spaces to move, related to geography, road safety, environment, health, among others.

In the case of Yupi 10, the basic rules of the game correspond to the following tasks. First the user has to choose a mission for the ship. In the prototype, we include nine missions (figure 7), with increasing levels of difficulty that correspond to second grade. All missions have an "audio-problem" form and represent acted out situations in which the captain and lieutenant of the ship take part. For example, there is an emergency and the number of oxygen tanks has to be determined through a subtraction or addition operation.

Fig. 7. Missions with increasing levels of difficulty

The next step is to use the ship's color board to graphically represent the problem data (figure 8) and execute the corresponding arithmetic operation. Finally, the result is verified in the option menu in order to go on to the next mission.

Let's see how an addition operation is carried out (figure 9). Let's suppose we have to add 18 + 5. First we represent number eighteen by lighting eight units and one ten (figure 9a). Then we add the five units, but as we only have two available circles (figure 9b), we have to exchange the ten units for a ten. For this purpose, we turn off the entire red column with the upper circle and we light up a circle in the blue column (figure 9c). Then we continue adding the three remaining units and at the end the total appears represented: twenty-three (figure 9d).

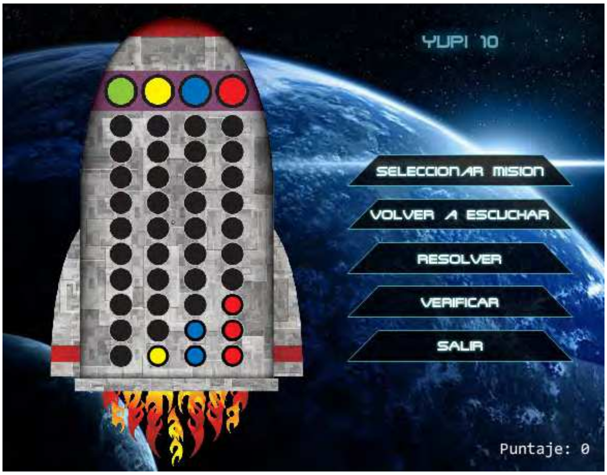

Fig. 8. Color Board with data and option menu

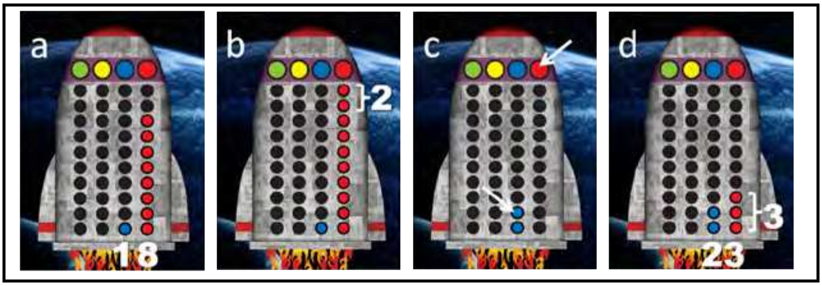

Fig. 9. Addition example (18 + 5 = 23)

In a subtraction operation, the process is the other way around (figure 10). Let's suppose we want to subtract 23 – 5. First we represent number twenty-three (figure 10a). Then we subtract number five, but as there are only three circles available (figure 10b), we have to exchange a ten for ten units. For this purpose, we turn off a blue circle and we light up the entire red column with the upper circle (figure 10c). Then we continue turning off the two remaining red circles and at the end we have the subtraction result: eighteen (figure 10d).

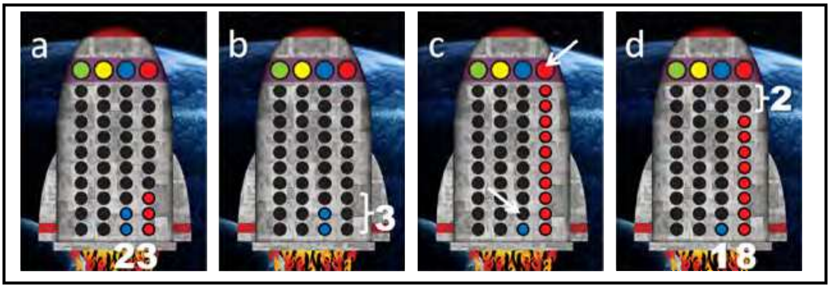

Fig. 10. Subtraction example (23 – 5 = 18)

2.3 Interactivity and sensory elements

In relation to the educational videogame design, some authors state that unlike commercial videogames, to have very limited budgets "[…] has huge consequences in the quality of graphics and the level of interactivity and consequently, in its capacity to attract reluctant students." (Buckingham, 2008: 155). We believe that educational videogames should not be compared to commercial videogames but to school books, in face of which they are more attractive. In addition, there are studies that warn about the distracting effect of drawings that are too complex or real (Medina, 2010: 279). On the other hand, regarding the symbolic game - which has great influence in developing children's thoughts - experts affirm that playing materials "[…] the more simple and functional they are […], results obtained from the symbolic game will be positively better and greater (Licona, 2000). That is why in the case of Yupi 10 we chose a simple interface design to help give context to the game and facilitate interactivity.

Educational digital recycling of traditional material requires the identification of essential actions, which should be kept and which should be eliminated or modified. Lighting and turning off circles in Yupi 10 is an interactive way of putting and taking away seeds in the physical *yupana*. This is a key aspect because they are actions that represent addition and subtraction operations. Another important factor in an interactive application is to decide if certain function should be automatic or manual. For example, in the Yupi 10 exchange process, there is the technical possibility that after completing the ten circles in a column, all "automatically" turn off and one lights up in the following column; but it is preferably for the user to do it "manually" - like in the traditional *yupana* - so the person can assimilate decimal system equivalences better. In the case of the Disney multimedia we mentioned before, if the green color does not appear in an automatic or instant form but rather in a mechanic or progressive way, it would surely result in better learning on the blend of basic colors. Digital technology makes it possible to reproduce or strengthen both automatic processes, typical of the industrial society, as well as the manual systems, inherent to traditional society.

According to neuroscience experts, it is convenient for all educational material to be multi-sensorial: "When the sense of touch is combined with visual information, learning improves in almost thirty percent." (Medina, 2010: 244). It is also stated that nerve endings on our fingertips generate brain activity that helps in understanding. When you understand what is being taught, several brain areas are activated, whereas when you memorize without sense, the activity in nerve cells is much poorer (Fernández, 2010: 5). Several years ago, in relation to movies, Michel Chion (1993: 10) proposed that there are transensorial influences between what we see and what we hear. According to this author, you do not see the same when you hear and you do not hear the same when you see. At present, with the boom of touch screens and physical recognition systems, transensorial influences in the media and teaching materials will become more frequent and varied.

In relation to Yupi 10, we have mentioned the exclusive audible nature of audioproblems. This decision seems to contradict the convenience for teaching materials to be multi-sensorial. However, we had several reasons to avoid the use of aiding images when presenting the problems. In the first place, several math teaching experts sustain that as of second grade, when children are introduced to arithmetic problems, which they have to read from their textbooks, they begin to lose the ability to listen that they developed in first grade. They also state that in daily life, the majority of arithmetic problems that arise and need to be solved are oral. Therefore, they recommend looking for an adequate balance in school between written and oral problems (Capote, 2005). On the other hand, audio stories require a higher level of attention and concentration, which helps children process and analyze information better. As Shanker (2010) indicates, the calmer, focused and alert a child is, the better will he be able to integrate sensory information received by his brain and assimilate it and organize his or her thoughts and actions.

2.4 Levels of difficulty and reasoning

Another important aspect related to problems was determining the way to write and classify them according to levels of difficulty. Several math teaching specialists indicate that in order to solve a problem effectively, boys and girls should make a global analysis of the text meaning, that is, to understand the problem formulation. In this sense, there is a semantic classification of verbal elemental arithmetic problems into four categories: combination, change, comparison and equating (Puig & Cerdán, 1988). Combination problems are the simplest ones and describe the relationship between two parts and a whole. For example: "There are 35 people at a meeting, 12 are men; how many of them are women?" Here, the unknown factor is one of the parts that make up a whole. Another possibility is for the unknown factor to be the whole: "There are 12 men and 23 women at a meeting; how many people are there in total?"

Change problems have a slightly higher level of difficulty. There is an initial amount, a change amount and the final amount. For example: "Ana had 12 coins, she earns 7 coins; how many coins does she have now?" Here, the unknown factor is the final amount, but it can also be the initial amount: "Ana had some coins, she earns 7 coins, now she has 19 coins; how many coins did she have at the beginning?" Another possibility is for the change amount to be the unknown factor: "Ana had 12 coins, she earns some coins, now she has 19 coins; how many coins did she earn?" These same change problems can be expressed in a decreasing way, replacing the expression "earning coins" for "losing coins."

The degree of difficulty of comparison problems is higher and shows a static relationship between two quantities: the referential one and the compared quantity. For example: "Juan is 8 years old, Ana is 13. How much older is Ana than Juan?" Here the unknown factor is the difference but it can also be the compared quantity: "Juan is 8 years old, Ana is 5 years older than Juan. How old is Ana?" Another possibility is for the unknown factor to be the referential quantity: "Ana is 13 years old and 5 years older than Juan. How old is Juan?" These same problems can be formulated in a negative way by replacing the expression "older than" for "younger than."

Equating problems are usually the most difficult and also imply comparisons between two quantities but using a connector of the type "as much as" or "equal to." For example: "Juan weighs 27 kilos, Ana weighs 18 kilos. How many kilos does Ana have to gain to weigh as much as Juan?" Here, the unknown factor is the difference but it can also be the compared quantity: "Juan weighs 27 kilos, if Ana gains 9 kilos she would weigh as much as Juan. How many kilos does Ana weigh?" Another possibility is that the unknown factor is the referential quantity: "Ana weighs 18 kilos, if she gains 9 kilos she will weigh as much as Juan. How many kilos does Juan weigh?" As in the previous case, these same problems can be expressed in a negative way by replacing "gain kilos" for "lose kilos".

The degrees of difficulty of these four categories are not absolute. There are studies that suggest that some specific forms of an inferior category are more difficult that other specific forms of a higher category. For example, the change form: “Ana had some coins, she loses 7 coins, now she has 19 coins. How many coins did she have at the beginning?”, is often more difficult than the comparison form: “Juan is 8 years old, Ana is13. How much older is Ana than Juan?”

This semantic classification of verbal elemental arithmetic problems puts emphasis not so much on children’s calculation skills but on their analysis and reasoning ability. Based on these criteria, we drew up the nine missions of the Yupi 10 prototype and we grouped them into three levels of difficulties: initial, intermediate and high.

2.5 Validation of the prototype and results

The challenge of every educational innovation consists in being able to turn knowledge objects into objects of desire. (Ferrés, 2008: 180). In this sense, during the qualitative validation of the prototype with three groups of children between the ages of 7 and 9, we could observe that the videogame awaken interest and curiosity, despite the simplicity of its design and the usual resistance math generates in students. However, we also noticed an inconvenience: some children listened to the audio problems too quickly and decided to do the problem - addition or subtraction - without thinking too much, almost by guessing and when they checked the answer and it said “error detected,” they simply carried out the opposite operation and they got “mission accomplished”. They noticed that by choosing the operation at random, they had a 50 percent chance of being successful, which encouraged a conduct similar to throwing dice to see what they got. As we mentioned before, audio problems were designed based on a semantic classification that requires analysis and reasoning. Consequently, the children’s attitude contradicts the educational purpose of the multimedia. In order to correct this defect, it would be convenient to include in the game instructions a score system: winning points for each right answer and losing points for each mistake. This reward and sanction system is usual in some commercial videogames and we believe it could be useful for Yupi 10, despite the fact it is a behaviorist strategy. During the validation, we tentatively assessed this. When we warned the children: “think well, if you make a mistake, you can lose points,” they listened to the audio problems again to analyze them better.

Here we need to ask ourselves about the importance of chance in playing activities. In football for example, chance is a factor that goes beyond players’ ability and that in addition to adding interest to the match, it can influence the final result. Would it be appropriate to add the chance component into an educational videogame? We believe that eventually it could be used in aspects not related to those we have called basic rules of the game (unless understanding the notion of “by chance” is the educational objective of the material). Thus, this would increase the participants’ interest without affecting the expected learning.

Another inconvenience we noticed during the validation was that some children, instead of using the ship board to show the problem data on a graph and carry out the respective operation, made mental calculations (or used their fingers) and only used the interface to check the result, especially the easiest problems. We got the impression children wanted to find the answer very quickly and thought that using the ship board was too slow. Probably this attitude is influenced by the customary practice of commercial videogames in which the reaction speed is a key factor in success and also by the habit of some teachers to value results of an operation more than the process followed. In any case, it is an attitude that does not contribute to the purpose of incentivizing reflection and reasoning. A way to overcome this inconvenience would be to include in the multimedia the possibility of checking not only the result of the operation but also some of the previous steps: for example, representing the problem date adequately and choosing the addition or subtraction option correctly. Thus, we would be promoting a methodic and progressive attitude in children in order to reach a goal.

Regarding teachers, a notable result of validation has to do with its mediating function between the material and the children. In a previous research on audiovisual riddles (Montalvo, 2011: 130) we maintained that such function consisted in facilitating “clues” or individual aid to students and that this type of personalized tutoring could hardly be assumed by a machine because technology tends to standardize users. The validation of Yupi 10 supports this criterion. The videogame test allowed us to experiment situations in which we had to assume the role of an aiding facilitator suited to each child. In one case, it was necessary to teach how to represent numbers on the ship board. In other cases, we had to put illustrative examples or use graphs or diagrams - made on the spot - to clarify the sense of an audio problem. In general, we verified that there are many differences and gaps in the students’ previous knowledge, which implies that the mediating participation of the teacher would be essential if we want to achieve significant learning processes with Yupi 10.

3. Conclusion

In this chapter, we have systemized the experience of designing a multimedia application in the form of an educational videogame based on a traditional material of proven educational effectiveness. The study of the Yupi 10 case allows us to affirm that educational videogames are really educational when the basic rules of the game (structural principles of creative design) fully agree with the material’s learning objectives. Otherwise, they only incentivize the review of previously acquired knowledge and correspond to a multimedia application category that conceive the educational process more as the transmission of information rather than the building principles of learning. On the other hand, it is worth highlighting the way math problems are formulated in Yupi 10, which seeks to privilege reasoning over calculation skills. We believe it is a very appropriate approach for current times because in a society where there is an abundance of accessible data, knowing how to reason is one of the competencies needed to analyze information and turn it into knowledge. Finally, in relation to interactivity, we must point out the educational value of manipulative actions, which are usually minimized as opposed to multimedia visual and audio aspects. Therefore, maybe we should rather call educational videogames “videotoys” so we can always keep in mind their multisensory nature.

Regarding the educational digital recycling, we believe this is a timely strategy for this transitional era, in which we can foresee the future without losing sight of the past. In order to appreciate the creative flexibility of the digital society, we have to imagine it as an inclusive culture capable of taking in and strengthening the best educational resources, both from traditional society as well as from the industrial society. Could it be that maybe we are so fascinated with new technologies that we forget about the good educational practices of the past? How many valuable traditional resources created by anonymous teachers in small schools could be digitally recycled to increase their benefits and launch them to the world? Digital culture knows no time or space boundaries. The Inca *yupana* was created more than 600 years ago in a long-gone society and was rescued as educational material at the end of the last century. Today, by digitally recycling it as Yupi 10, maybe it will have the opportunity of starting a new life cycle.

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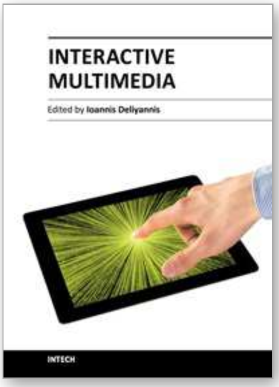

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Interactive multimedia is clearly a field of fundamental research, social, educational and economical importance, as it combines multiple disciplines for the development of multimedia systems that are capable to sense the environment and dynamically process, edit, adjust or generate new content. For this purpose, ideas, theories, methodologies and inventions are combined in order to form novel applications and systems. This book presents novel scientific research, proven methodologies and interdisciplinary case studies that exhibit advances under Interfaces and Interaction, Interactive Multimedia Learning, Teaching and Competence Diagnosis Systems, Interactive TV, Film and Multimedia Production and Video Processing. The chapters selected for this volume offer new perspectives in terms of strategies, tested practices and solutions that, beyond describing the state-of-the-art, may be utilised as a solid basis for the development of new interactive systems and applications.

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