

Playing digital cards as an assessment tool for numerical abilities

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Abstract

Playing cards is an entertainment activity that can be exploited to build game-based applications to train and assess different aspects of cognition. In this paper we describe how this approach can be applied to the assessment of numerical cognition, with the description of Baldo, a suite of physical and digital card-games, strongly based on scientific theories of numerical cognition.

Keywords: Tangible Educational Materials; Numerical Cognition; Game-Based Assessment

1. Introduction

Playing cards, as other kind of games, is an activity that can be fruitfully integrated in Game-based learning. In fact, one of the most significant advantage of playing cards is the entertainment it provides, at different ages, that can be exploited to favor some kind of learning.

Children play cards, adolescents play cards, adults and elder people play cards. The literature on Game-based learning has clearly indi-

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cated (Oblinger, 2006) that one of the most suitable methods of entertaining children include board games and card games. For elder people playing cards is one of the most widespread ways to spend times.

Together with the entertainment aspect, playing cards involves a number of cognitive functions, including memory skills and strategic thinking ability; in the case of cheating also the theory of mind (Wellman, 1992) must be used, as it is necessary to represent and manipulate others' mental state, the beliefs on the game to foresee playing behavior.

Playing cards is also useful at social level: this activity can strengthen family ties and friendship bonds and playing cards with the family can help build children's confidence (Li & Zhang, 2015). Card games can stimulate the brain and help fight memory loss (Fairfield, Mammarella, & Di Domenico, 2015). It also helps people to stay away from loneliness and depression. Along with social, mental and educational benefits, playing cards also provides an exercise to different body parts including mainly eyes and hands. Card games can encourage hand-eye coordination and help stimulate and exercise one's mind. Shuffling and dealing may help quicken the reflexes. These games offer all these benefits but this is true only when playing cards is used solely for a family and social purpose. Addiction in gambling cards can ruin one's social, family and economic life (Gupta & Derevensky, 1996).

Playing cards, obviously, implies counting, which is the focus of the present paper, where we introduce a physical and digital system for the assessment of numerical abilities.

In fact, together with the training it offers, related to the different aspects described before, playing cards can be used to an assessment based on games for different cognitive functions, an example of what has been called Game-based assessment (Mislevy et al., 2014, 2016; Kim & Shute, 2015).

It is interesting to underline that often cards of different kind are used as tangible educational materials in well-established pedagogical approaches (Di Fuccio, Ponticorvo, Di Ferdinando, & Miglino, 2015; Ferrara, Ponticorvo, Di Ferdinando, & Miglino, 2016). Just to cite, the Montessori method (Montessori, 2013), which is recognized as one of the most effective approach in children education, includes a

wide variety of materials that favor active exploration and foster all children potentialities. The materials are, in many cases, manipulatives, physical objects specifically designed to foster learning and they include cards.

In this paper we will focus on how to apply this approach to some aspect of numerical and mathematical cognition with a tool that has been designed in order to favor and, at the same time, assess mathematical abilities at cognitive level.

2. Numerical and mathematical cognition

Numerical cognition represents one of the four core knowledge systems at the foundation of human knowledge (Spelke & Kinzler, 2007), that allow to better adapt to environmental conditions and face many evolutionary challenges.

The relevance of numerical cognition, considering humans, is evident if we adopt a developmental approach to cognition and consider the developmental pathways that lead from the basic abilities that human beings manage since the beginning of their lives to the formal education in school context that will start later during infancy. It is possible to observe many possible outcomes in numeric, and later mathematical, achievement, even if the starting point is comparable: differences in math achievement are consistently reported at different age, between genders (Spelke, 2005) and in different cultures (Stevenson, Chen, & Lee, 1993).

These observed differences are not related to disparity in the starting condition, as the natural endowment to deal with numeric knowledge is shared between humans, so it is likely that they depend on other factors, probably related to cultural and socio-cognitive factors, including education. What do we mean by natural endowment?

Human beings, as well as the other species (Boysen & Capaldi, 2014; Davis & Pérusse, 1988) are able to deal with numerical information without being instructed to do so. This is a clear indication that there are some innate abilities and some others numerical skills that can be acquired with the proper instruction, especially in human beings.

Counting is an ability that is possessed by many species: extracting numbers from experience, distinguishing major from minor quantities, showing surprise if a calculation is wrong, distinguish in a rapid and accurate way a small amount of objects and elements, an ability called *subitizing* (Kaufman, Lord, Reese, & Volkmann, 1949), are the basis of numerical abilities that represent the common basis of numerical cognition.

In the case of humans, this is the basis on which more sophisticated abilities are built on, a natural predisposition for future academic abilities that can be measured and enhanced with the appropriate intervention.

Toddlers are sensitive to numerical properties, as they detect differences between small numbers and have quantity expectations, so much as numerosity variations may cause disappointment or astonishment. This evidence correlates with the theory of innate numerical abilities (Butterworth, 1999; Girelli, Lucangeli, & Butterworth, 2000), according to which we have got, since the first weeks of our lives, innate numerical skills to classify small sets of elements (4-5 items); later, the culture teaches us how to use the numbers competency in a more advanced manner.

Many evidences indicate that human infants possess an intuitive sense of number, the so-called number sense (Dehaene, 2011). It is connected with the Approximate Number System (ANS) (Halberda & Feigenson, 2008; Gilmore, Attridge, & Inglis, 2011): a cognitive system that supports the estimation of the magnitude of a group with more than four elements without relying on language or symbols, together with the parallel individuation system, or object tracking system for smaller magnitudes.

Number sense in infancy is strongly connected to math skills in childhood, so that it is possible to predict math achievement starting from the number sense at very early ages. In the study by Starr and colleagues (Starr, Libertus, & Brannon, 2013), authors report some results that allow to claim that the number sense, before language acquisition, “may serve as a developmental building block for the uniquely human capacity for mathematics”. In fact, in their work, the cited authors show that the performance on numerical preference scores at

6 months of age is correlated with math test scores at 3.5 years of age. The number sense can be a relevant facilitator in the acquisition of numerical symbols and mathematical abilities.

The study by Starr and colleagues traces another interesting and useful connection between number sense and mathematical abilities, as it suggests that a stronger number sense predicts later stronger numerical abilities, opening the way to the possibility to design educational interventions, addressed to strengthen the number sense so as to improve mathematical achievement in later years. In other words, the natural endowment we have talked about before, can be strengthened, with an appropriate training in the domain of numerical cognition. The necessary pre-requisites for these intervention is obviously the assessment of these abilities.

2.1 Numerical cognition: the triple code model by Dehaene

Currently, the leading model on numerical cognition is the triple code model proposed by Dehaene (1992). According to this model, three representational codes for number exist: Arabic digits, verbal number words, and analog non-symbolic magnitude representations; these systems are different at functional and neural level, as each of it is served by a functionally dissociated neural substrate. The visual Arabic number form corresponds to the numeric symbol, for example “4”, the auditory verbal word frame corresponds to the word “four” and the analog non-symbolic magnitude representation corresponds to the quantity, for example four dots (••••). These different codes are connected to different mathematical abilities. The Arabic number representation is involved in written exact arithmetic that is formally taught at school; the analog non-symbolic magnitude representation is connected to the approximate number representation and allows to make number comparison and approximate arithmetic; the verbal number representation is connected with counting and mental exact arithmetic (mental calculation).

The ability to deal with these different representations and to progress to more sophisticated ones is relevant in determining numerical

and mathematical abilities and should therefore be addressed in a successful educative intervention.

2.2 Mathematics in formal and informal educational contexts

If we now move to the educational context, it is important to underline that the pre-requisites on mathematics are important predictors of school achievement and success.

In this respect, school readiness, a multidimensional concept that identifies the competences that a child needs before entering school (Snow, 2006), can be decisive. Crucial indicators are the pre-requisites of learning, knowledge and abilities that develop before acquiring reading, writing and calculation skills (Shaul & Schwartz, 2014).

Literature highlights consistently the importance of pre-requisites of calculation for the success in primary school and beyond (Hindman, Skibbe, Miller, & Zimmerman, 2010; Romano, Babchishin, Pagan, & Kohen, 2010).

Pre-requisites and later achievement correlation offers threats and opportunities. The transition between pre-requisites and advanced math skills can be problematic as it implies a rapid change of perspectives and methodologies: the embodied elements leave the pace to symbolic ones. In kindergarten children use their fingers or physical objects to count, but quickly, after a single summer, the learning approach becomes abstract, mainly relying on working memory (Ashcraft & Kirk, 2001).

Some children are able to follow this quick step, some others do not and this can generate difficulties in treating numbers. Considering the Triple Code Model, the transition between the approximate number representation and the Arabic and verbal number representation can be uneven.

On the opportunity side, if pre-requisites are strengthened with an appropriate intervention also later achievement at school can be improved.

This is what happens in formal educational context, but some problems may arise also in non-educational context: it is frequent that

children are stimulated to develop language skills long time before school starts. Parents are very concerned in facilitating children with language acquisition, favor and promote linguistic skills, giving examples and constantly correcting mistakes and also proposing many activities in a leisure way, for example reading tales. This doesn't usually happen with mathematics. When children encounter math at school, the concepts can be completely new, and the only preparation they have, comes from the messages they can have extracted, as the idea that math is hard, or the stereotype that girls aren't good at math.

This means that children have not developed any positive association with math before school, as happens with reading. Being unfamiliar with numbers or calculus may even generate negative feelings towards math, an issue we will describe in the next section.

3. Emotional dimensions related to numerical cognition

If we ask people who like math why they do, the replies sound like these "It gives me the best feeling in the world", "Math is fun and interesting and entertaining"; "I have always been good at math"; "Why I like math? First, I was good at it, I found it fun that everything was logical"; "Mostly I find it really fun. It's like a gigantic puzzle".

It seems that people like math because they understand it and have positive feeling about it. Some results from research in mathematic achievement (Liben, 2015), can help clarifying which factors determine math liking. An useful hint comes from a study commissioned by Microsoft, which suggested that male students are more interested in mathematics and STEM studies because they have always enjoyed games and toys that are focused on this area.

But mathematics is not loved by all. A wide line of research has underlined that mathematics and related subjects can generate mathematical anxiety, a feeling of tension or fear which appears when a person is faced with mathematical content (Morsanyi et al., 2016). Which are the causes for math anxiety? Even if a lot of research from different domains has addressed this question, there is not an univocal

answer. One explanatory factor can be the educational methodology which becomes immediately too abstract, as introduced earlier.

Another important factor is motivation. In a quite recent review on the theme, Rosenzweig and Wigfield (2016) have analyzed numerous studies, both experimental and quasi-experimental, targeting adolescents' motivation for STEM subjects, underlining that motivation is a core factor in math achievement.

Related to this problem is the measurement of motivation towards mathematics and STEM. Some tools are addressed to science motivation, for example the Science Motivation Questionnaire - SMQ II (Glynn, Brickman, Armstrong, & Taasobshirazi, 2011), some others assess interest in the STEM disciplines and careers - STEM Semantics Survey and the STEM Career Interest Questionnaire (Tyler-Wood, Knezek, & Christensen, 2010), some are specifically devoted to explore math anxiety, but there is no standard procedure to assess mathematics and STEM motivation. It is worth underlining that the cited assessing tools are addressed to adolescents, whereas few attention is devoted to early childhood and other age groups, which can be more effectively treated with an approach based on Games, as we will see in the next section.

4. Game-based learning and assessment for numerical cognition

Game-based learning (GBL) can be effectively applied to the improvement of numerical cognition, as it has some relevant features that are particularly useful for this goal.

In general, playing every kind of game, at every age, involves the player in a challenge, of various kind, that forces the player to learn something, i.e. the elements and the dynamic of the game itself or other contents that are connected to game scenarios, characters, etc.

Playing games implies learning as the players are forced to deal with goals, rules, adaptation, problem solving, interaction, that are often proposed to the learner in the form of a story (Di Fuccio, Ponticorvo, Ferrara, & Miglino, 2016; Ponticorvo, Di Ferdinando, Marocco, Miglino, 2016; Ponticorvo, Di Fuccio, Di Ferdinando, Miglino,

2017; Ponticorvo, Rega, Di Ferdinando, Marocco, Miglino, 2018). What is relevant for numerical cognition is that games are able to offer enjoyment, involvement, motivation, creativity, social interaction while conveying some useful information or content.

A comprehensive review on digital games by Tobias, Fletcher, & Wind (2014) examines the empirical evidence on the effectiveness of using video and computer games to support learning process. The authors underline people can learn from games in a particularly effective if:

- the game design process supports the acquisition of the specific knowledge and skills the games is meant to transfer;
- a good instructional design is integrated with the highly motivating features of games.

In the case of digital games for learning, two dimensions must be harmonized in order to reach educational results, the first one is connected to psychology and education, in particular to the cognitive, motivational and affective dimensions of the learning process; whereas the second one is related to the use of Information and Communication Technology (ICT) and the technology serving for educational purposes.

If we consider what has been discussed in the previous section, it is clear that some features of games and digital games, can be particularly useful in affecting positively learning, but also in producing positive feelings about a specific issue.

The first feature is connected to motivation and engagement (Al-sawaier, 2018): games are motivating (Abdul Jabbar & Felicia, 2015) and can lead to what has been called “flow experience” that results in deep engagement and, consequently, enhanced learning.

The second feature is related to the time on task: the motivating and involving aspects of game lead student to spend more time on task and there is a strong correlation between the time spent of task and learning outcomes, as indicated by literature since the 80s (Karweit, 1984). This feature is related to informal educational contexts too. If the player is motivated to play the games with educational content, the time dedicated to it will not be limited to school and formal contexts, but will cover free time and informal learning. Jirout and

Newcombe (2015), confirm this affirmation: whereas language skills acquisition is supported at home by caregivers, math skills are stimulated in school context only. But, if a little help is given, for example, in the form of a mobile app, math skills improve. This means that skills related to mathematical achievement can be trained also in early childhood, even before school entrance, also in home context (Berkowitz et al., 2015). It is interesting to underline that this math skills improvement is more evident in the case of caregivers who are anxious about math.

The third feature depends on the fact that, through games, player learn not by being told, but by doing, that is to say, they experiment experiential learning. Experiential learning activities can help students to remain focused, as learning actively makes less likely to become bored; to learn differently, as they are more engaged emotionally and learn faster, because learning by doing requires problem-solving and critical thinking that accelerate learning and improve content retention.

A good example of how GBL can be applied to numerical cognition, in particular to arithmetic, is provided by *Zombie Division* (Habgood, 2015), a game to learn arithmetic where the player is an ancient hero who faces skeletons wearing numbers. The player can use several attacks, each one corresponding to a kind of division operated on the number linked to the target enemy. The player must take care of matching attacks with opponents through divisions, as enemies cannot be divided without the required attack.

Considering the cognitive side, a review by Drigas and Pappas (2015) reports representative studies evaluating the effects of video games on mathematics achievement, memory, attention and cognitive skills. These studies indicate that video games can be useful in mathematics education, supporting the comprehension of fundamental concepts and motivating them to see positively mathematics.

Generating positive feelings is the complementary pathway to promote mathematical achievement.

In the framework of GBL, these tools can be used for assessing mathematical abilities or related abilities such as reasoning (Ferrara et al., 2016) and soft-skills (Marocco, Pacella, Dell'Aquila, & Di Ferdi-

nando, 2015) and emotional at different ages, becoming game-based assessment. In GBL, also for assessment, the game dimension is useful as it involves people, not boring them and also allowing to assess people on a longer time-scale; it allows to observe people behavior while they do something, rather than asking for self-reporting.

5. A Game-based tool for assessing numerical cognition: Baldo

In this section we describe a system with physical and digital card games named Baldo that has the same logic structure of Italian gaming cards but is also based on the triple code model by Dehane. In the deck the three codes (text, numerical and analogical) are mixed and the numbering starts from 0 and arrives to 9. This is linked to the decimal notation and is a small destabilization to stimulate in the minds of players a constant workout.

Moreover there are special cards (basic arithmetic operators such as $+$, $-$, \times , $:$, $=$) that can be used to propose questions and mathematical problems on the table.

Baldo exist in two versions: physical and digital. In the Baldo physical side the tangible cards allow active manipulation of concrete objects which is relevant, in accordance with the Embodied and Situated Cognition (Clark, 2008) on the psychological side and to Montessori (2013) on the pedagogical side, to favour learning.

In the digital version of the card game players can choose between different decks (mixed codes, traditional card decks etc.) and play against an artificial agents trying different card games. These games include games from the Italian tradition.

The virtual opponent has an emotion module, able to adapt his facial expressions with the progress and his score in the game. This enables to take into account the emotional dimension of the game and the connections between cognitive and emotional dimensions.

In the digital version of Baldo, along with the card games to be played in multi-player mode, there is also a single-player game that consists in selecting the card with the highest value between 2 cards. It records the speed of the selection on 20 attempts.

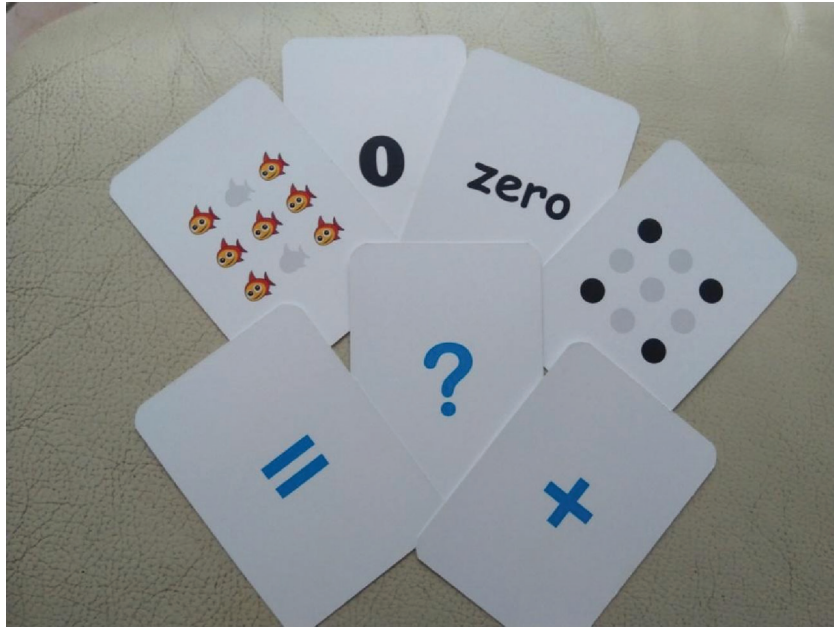


Figure 1. Baldo physical cards with the different codes and the special cards



Figure 2. The player and the virtual agent in the game (Italian Version)

The application allows to test people, including children, on the shift speed between the different codes which is, as reported above, a pre-requisite for advanced mathematical skills.

Together with assessment, this game is also useful to train the ability of moving between analogic representation, connected with the natural endowment described above and the symbolic one, connected to formal education in maths. During the game-play, the player is forced to make rapid mental calculation with different codes, thus exercising in a fun context even without realizing it.

6. Conclusions and Future Directions

Using cards both physical and digital can be a very effective way to assess numerical skills. Moreover, using these materials allows to exploit the embodied dimension augmented by the chance to record almost every aspect of children-game interaction. In fact, learning approaches focused on embodiment underline that action can support educational objectives and, in the case of numerical cognition, help the transition between analogic and symbolic dimension which is crucial in math learning.

Another important aspect is related to the use of these tools in different context, included non-formal educational contexts such as home. Learning today takes place in a context of new interactions between formal and informal learning, the changing role of teachers, the impact of social media, and the children active participation in learning activities. Learning cannot be confined in schools walls or training classroom, but happens in new contexts of interaction.

The next step will be to extensively test these tools with a longitudinal and experimental procedure that will follow groups of children at different ages to verify if the use of these tools can be valid and affordable to assess numerical abilities and later math school achievement. Moreover, Baldo will be developed to become an hybrid game joining physical and digital sides of the game and the emotion module will be used in studies involving the social dimension and its connec-

tion with numerical abilities, as pre-requisites of calculation can be affected by emotional factors.

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