Gamification and Coding to Engage Primary School Students in Learning Mathematics: A Case Study

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Abstract: This paper describes a pilot educational project made in a Primary School in Italy (*Scuola Primaria Alessandro Manzoni* at Mulazzano, Milan) implemented in 2016 and 2017. The project was born from a specific request: the school aimed at improving the results achieved by students aged 7 during the National Tests for Mathematics since they registered performances lower than the National Average. In this context, we supported teachers providing information tools and methods to improve performances. Our aim was to develop new game-oriented approaches to problem-solving, mixing our different experiences and competences (organization design, information technologies, psychology). We provided a broader spectrum of parameters tools and keys to understand how to achieve an inclusive approach personalized on students, involving them and their teachers in the project. This cooperative approach allowed us to collect interesting observations about learning styles, pointing out the negative impact that standardized processes and instruments can have on self-esteem and consequently on the performance of pupils. We argue that addressing pupils in considering mathematics as continuous research and development can increase their performances in National Tests execution. Children free to realize their own experiments and observations dramatically improve their involvement and curiosity about Mathematics.

1 INTRODUCTION

In Italy, students are required to take the INVALSI (Istituto Nazionale per la VALutazione del Sistema dell'Istruzione) test. INVALSI is an Italian government institution that submits the annual standard tests to every Italian school in order to evaluate the National Education System. The tests are formulated following the European guidelines, and they are standard, focused on Italian (language and literature) and Mathematics.

According to National Education Programs, the learning objectives for the second grade of primary school students:

- Acquiring a positive attitude towards mathematics.
- Guessing how the mathematical tools are used and useful in day-by-day practice.
- Being confident in mental arithmetic with the natural numbers.
- Understanding texts involving logical and mathematical aspects.
- Describing the procedure to follow in problem solving and recognizing the different solution strategies.
- Reasoning with assumptions supporting their ideas and comparing different points of view with classmates.
- Developing cooperative and collaborative attitudes.

INVALSI tests represent a big deal for students, always stressed by being assessed (Pagani and Pastori, 2016). Also for this reason, results might not correspond the real skills. Thus, the aim of the present work was to help them improving their performance at the INVALSI test by developing Information

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Technologies Supports and Game-oriented teaching strategies.

Our education approach may be effective in reaching specific educational aims (e.g. math skills), empowering psychosocial, and developing more general thinking skills, which might be included in the wide construct of creativity (Lucchiari et al., 2018). In order to think creatively, it is crucial to enable children to live rich experiences, so to enhance imagination, provide different perspectives and nourish flexible thinking. In order to develop creativity and imagination in a child it's vital to provide stimuli and methods to connect them by different angles. In this way, school-based activities will allow children to approach problems in a variety of disciplines as well as everyday life (Rogers, 2012). The Organisation for Economic Cooperation and Development (OECD) highpoints creativity as one of the most important learning goals for the 21st century (Lucas et al., 2013).

Several studies highlighted the importance of the creation of an appropriate learning environment, especially aimed at promoting and support students' creativity and divergent thinking (Lucchiari et al., 2019). Here we are suggesting that technologies and cognitive psychology may cross-fertilize educational sciences in order to produce inspiring learning environments.

2 METHODS

2.1 Participants

The study was conducted at the Primary School "Alessandro Manzoni", in Lodi (Mi), Italy with 7-years old students, whose registered performances were lower than the National average, showing the need to increase their interest in scientific disciplines.

The project involved 23 boys and 23 girls of two different secondary Classes (24 children in a class and in 22 children in the other). Also, 3 teachers were involved. They were not new to innovative projects since they already realized innovative lessons in past years developing interdisciplinary projects using mathematics as a "meta-language" (Coltman, 2007; Llinares and Valls, 2010; De Vecchi et al., 2016).

2.2 Tools

Several didactic games were developed to help students to overcome the fear of the test and to find a personal key to apply a problem-solving approach to scientific disciplines. Specifically, we composed didactic materials for teachers, consisting of laboratorial programs on specific lessons oriented to involve students in subject-related experiments in the classroom and some tests allowing teachers to better understand students' features (Entwisle and Ramsden, 2015).

Overall, in designing the laboratories we considered the need to:

- give space to meta-reasoning to link what is being done now with the general educational activities (in some cases even with the INVALSI tests);
- promote the participation of all, even in different moments;
- increase the psychomotor activation, motivation, and curiosity through some actual playing time;
- use the "thinking aloud" of children as a basis for the study (Short et al., 1991);
- increase the number of specific feedback even in different ways (emotional, cognitive);
- always differentiate between medium / long-term objectives and short ones.

A set of maths trials has been used to assess maths skills.

The test we have used was based on the assumption that mathematical competence is a multidimensional construct. It is, therefore, important to explore all of these dimensions, albeit through short sub- scales. In particular, we have evaluated the following dimensions:

2.3 Procedure

The first step of the project consisted of a cognitive and psycho-social analysis of the classes, conducted with the support of the teachers. Then, we observed if students' behaviour related to psychological and cognitive parameters correlated to the mathematical skills. All the information collected allowed us to design a gamification strategy to help students to find their personalized approach to mathematics. We will focus on those involving technological tools.

2.3.1 The Observation Phase

During the observation phase, we incouraged teachers and pupils to use computers, Interactive Whiteboards (LIM) and the game Angry Birds, to verify if these technological tools could help to catch the children's attention in order to empower their learning skills (Papadakis, 2018). Many of the students already knew the game and the characters, so they could have been easily involved in the activities, also soliciting comments and generalizations. Moreover, in each class, the teachers immediately identified a pupil able to work on computers, initially supported by the teachers and after autonomously, acting as a helper for the other students, according to a peer-to-peer support approach (Herrera et al., 2007). In this scenario, the teachers assumed the role of “primus inter pares” instead of being a sole guide.

Figure 1: A lesson with Interactive Whiteboards and personal computers.

The aim of applying these tools consisted in teaching children the algorithmic thought that is the ability to organize a series of instructions to achieve a simple goal. This approach stands at the basis of the so-called computational thinking, already studied in literature in the light of coding tools such as Scratch (Papadakis et al., 2016). Computational Thinking is, indeed, important to develop the ability to organize the instructions to perform specific tasks. In general, the concept of computational thinking is not to be understood in a legal way, as a kind of higher thought, more free, creative, heuristic. In our vision, the development of a computational thinking approach must be considered as a powerful way to improve performance in logical-mathematical tasks and, more generally, in the formal problem-solving.

2.3.2 Phase1: Coding and Robotics Laboratories

Most children’s problems especially in INVALSI test consists of the so-called "narrative" problems, i.e. those problems where narrative text hides the requests for calculation. This kind of problems causes anxiety to children (often even to adults) because the required steps to find a solution to the problem are not easy to identify. We faced the challenge of how to teach pupils to extract meaningful data and to apply the so-called "algorithmic mentality", that is the ability to break down the main problem in a series of sequential (or not) steps, connected to each other, to come to the final solution. This latter is the definition of a coding activity. Indeed, coding, in general, allows teaching the algorithmic approach in a practical and funny way, allowing children to create something. Moreover, in robotics coding is even more intuitive and simple, because it becomes concrete (children can see the result of the programming directly through the robot's actions).

Considering literature, we chose to run two laboratories, based on Scratch programming (Papadakis et al., 2017; Papadakis et al., 2018; Papadakis and Kalogiannakis, 2017) and on Lego Mindstorm robotics kit. To start coding activities and orient them to our purposes, we created some examples of transformation of INVALSI problems in activities to be realized through Scratch and through the robot kit. The activities have been designed to help children to train and develop on one hand problem analysis skills and ability in the decomposition of problems in simpler steps (algorithmic mentality and problem-solving); on the other visuospatial abilities.

Scratch (https://scratch.mit.edu/) is a free online platform developed by MIT (Massachusetts Institute of Technology), specifically designed for children in early school years. Through Scratch, children are able to create interactive stories, animations, and games. Coding is realized by blocks (simple pre-constituted modules). Scratch conveys the concepts of sequence and interactions of actions to be implemented, allowing children to create even complex instructions. This approach allows learners to separate the essentials of a problem from the narrative, presenting the question visually.

Compared to other platforms, i.e. *Code*, Scratch requires greater involvement of the students. The problem is not presented by the teacher but it spontaneously arises, as a creative process, soliciting the development of attitudes in individuating and analyzing a problem, and researching a solution (the problem-solving approach). The teacher can simply illustrate some projects to the students, also asking them to replicate these examples.

Programming by block in Scratch does not require to retain anything by memory, Students will only need to remember the basic concepts (what a sprite is, the possible actions, and so on). Then, recognizing the corresponding blocks and positioning them in the area on the right side of the stage, they can setup and test the programming steps. All the objects are “self-explanatory”.

We asked teachers to prepare the lessons following some specific steps:

- Show students several examples of projects, different in goals to achieve. In this way, teachers can stimulate children in proposing their own project to realize (formulating the problem);

- Make visual representations of the problem on paper. Although the first attempt is not clear, the idea will be described in the steps the children think they need to realize it.
- Choose one problem for each student and, where there are not enough computers, organize small groups. Every group should realize the project designed by every participant.
- Publish the projects on the Scratch website, to motivate children and to trace their progress.

The teacher acted only as a tutor leaving full autonomy to children. In fact, a cognitive activity lead by personal motivation produces longer lasting results in terms of the development of logic, mathematics and scientific intelligence (Schiefele, 1991).

Children were then ready to design and realize autonomously their projects.

Lego Mindstorm, instead, is a kit providing all it is needed to create real robots that perform the actions planned by the learners. The kit includes a free visual programming tool (EVE) that can be easily used by the children of the first classes of primary schools to code even complex robot actions, after an introduction by the teacher (Papadakis and Orfanakis, 2017). On the Lego Mindstorm website, users can find videos, instructions, specifications of the blocks, that are the "units" that, connected together in a visual way, allow to completely program the actions of a robot. It is also possible to apply to the First Lego League Jr and participate in several contests (http://fll-italia.it/junior/2015/), motivating, in this way, children and enhancing their ability to compare with others, developing group cooperation to achieve a result. The Lego Mindstorm community is very active and therefore the content available, from which to take inspiration for classroom activities, are many.

From a methodological point of view, we devoted both the Scratch and the Lego Mindstorm laboratories to transpose visual-oriented, geometry and physics quizzes from the INVALSI test in coding, since these latter are compatible with coding activities.

In the Lego Mindstorm kit, a visual programming tool (EVE) is included. As in Scratch, EVE is a block-based visual programming environment, so both students and their teachers become confident with the new tool very quickly, due to an analogy-based approach.

In the activities made with the Lego Mindstorm kit, there has been no direct connection with the INVALSI's quizzes, because no problem could be directly translated in robotics. Moreover, all the activities performed with the robotics kit have been helpful to acquire and consolidate visual-spatial abilities and the problem-solving approach.

The labs consisted in a first step in introducing EVE to children, starting from analogy with Scratch. This step was essential, to reinforce their ability to proceed following the analogic approach.

In a second step, children have been guided in building the robots suggested on the kit manual. This practical activity was performed to reinforce the visual-spatial skills and the ability to follow a procedure, decomposing it in simple actions, that is what students are required in reading and understanding the INVALSI test.

Finally, students associated the actions programmed with EVE to a robot, to make concrete the result of their work. Following some simple instruction we provided them, expressed as they were short INVALSI test.

2.3.3 Project Phase2: Gamification

After Phase 1, we developed a set of laboratories involving children and teachers at various stages: graphics design, selection of mathematical games, test development, and game rules' improvement. This activity required a great investment of time and resources, but it allowed to integrate different disciplines: Italian language, art and design, mathematics and computer science helping children to train and enhance several intelligence forms: creative, synthetic, logical, linguistic, spatial, collaborative.

We developed several coding sessions inspired by INVALSI tests with teachers and we observed fear and boredom that many children perceive when they face an "examination" as INVALSI will be dramatically reduced using these devices and applying the game approach. Playing games, children will get used to address INVALSI questions, they will understand the language, the pitfalls and the resolution keys, just as they do when they play using APPs like: *Dino Dog – A Digging Adventure*, or *Mickey's Magical Maths World*, or *Secret Society*, or other games.

We applied Gamification approach to reduce pupils stress and fear of mathematics. We used game mechanisms to engage children in solving mathematical problems as "game challenges". Coding and Lego made the application of gamification very simple, as it allowed us to play with mathematics using reality as a test field. The sessions designed in this first phase allowed us to produce immediate feedback for pupils and teachers. Moreover "gamificating" math exercises the students had the opportunity to repeat the games several times, becoming familiar with numbers, operators and mathematical concepts (Hamari et al., 2014).

During this second phase of the project, teachers have been introduced also to the use of Brain Computer Interface (BCI) as a cognitive device to boost and empower learning. BCIs are EEG-based headsets simplifying the EEG medical device (Allison et al., 2007). Born in the context of gaming, non-invasive, they allow to collect electrival brain signal from the scalp of an individual through wet or dry sensors. The collected signal are then transformed into commands or analysed for research purposes. BCIs are low cost, as accurate as the medical devices, Wi-Fi or bluethoot connecte to a computer to collect and analyse brain rhythms. For these reasons, this cognitive technology presents a high portability and don not cause any discomphort in individuals wearing them, allowing a wide movement freedom in the experimental environments. Following literature (Başar et al., 1999), EEG-based BCIs collect the same medical device rhythms, namely alpha (7 Hz – 14 Hz), associated to meditation, relaxation; beta (14 Hz – 30 Hz), related to attention, active thinking, concentration levels; delta (3 Hz – 7 Hz), registered in children and associated with continuous attention activity (Leeb et al., 2006); theta (4 Hz – 7 Hz), generally related to emotional engagement (Cameli et al., 2016); gamma (30 Hz – 80 Hz), indicating a cognitive interpretation of multi-sensory signals. The possibility to collect the above brain rhythmsmakes BCIs particularly suited to investigate the mechanisms of learning, memory and attention, isolating reactions to specific stimuli (Bait and Folgieri, 2013). Indeed, these devices have been widely used in research, such as in registering the response to musical and visual stimuli and recognize the emotional valence (Folgieri et al., 2014; Folgieri et al., 2013; Folgieri and Zichella, 2012(a); Folgieri and Zichella, 2012 (b)); to study the process of visual creativity (Folgieri et al., 2014); in evaluating the emotive and cognitive response to stimuli, as in response to colors (Wiggs and Martin, 1998; Folgieri et al., 2015), to stereoscopy and monoscopy (Calore et al., 2012) and also the cognitive response to visual-perceptive stimuli (Banzi and Folgieri, 2012 (a); Folgieri and Zampolini, 2014), based on the concept of priming (Banzi and Folgieri, 2012(b); Soave et al., 2016).

Within the second phase of the project, we introduced BCIs in some practical lessons, to show to the teachers the great potentiality of these cognitive technology to empower learning skills in students, working on memory, attention and concentration. Then, we used the didactic games provided with the Neurosky (http://neurosky.com/) headset to show students the visualization of their attention and concentration levels during a game. In this way, students had a feedback (a bar indicating the level of attention) on their ability and became more conscious of their cognitive status.

3 RESULTS

3.1 Observation Phase

From the described activity, we observed that students had difficulties in encoding their own thoughts. Indeed, the generalization process did not appear linear. For instance, the transition from the instruction *"take a step forward"* to *"turn left"* appeared to be mediated by a complex understanding process. We, thus, made two considerations:

- The children need not only to achieve a specific outcome (i.e., "capture the pig and roast it"), but they also need to consolidate this result over time, through repeated trials and level advancements. Moreover, the children’s approach seemed to be heuristic-exploratory, driven by curiosity rather than by the search for a logical basis.
- The association with the INVALSI test appears more evident in this case. Thus, we hypothesized that the development of formalization strategies could allow children to face the problem-solving tasks present in the INVALSI test. Indeed, we argue that, to achieve this goal, children need to consolidate the proceduralization (through routines useful to address the problems, according to the instruction sequences) in order to understand the representation of a problem and, then, generalize the approach.

Interesting enough, during this didactic game-oriented activity, when children found new solving mechanisms, they spontaneously formulate meta-cognitive comments, suggesting them also to the teacher. Easily distractible children have been involved by others and the achievement of a milestone in the game acted as a reward and reinforcement for all the students, who were free to express emotionally themselves (they rejoice).

We considered these observations with the final aim of improving children’s performance in the INVALSI test. Since the results of any mathematical test are mediated by emotional and motivational aspects, which often act in a negative way, the INVALSI tests, regarded as not funny and difficult in their format, are generally associated to negative attitudes. Even students with high skills could "fail" simply due to a lack of motivation, causing a decrease in the levels of attention and inhibiting children's ability to find connections between the test's quizzes and the acquired skills. In this context, and on the basis of the observation made in the preliminary phase, we found out that students need to be supported in the development of a "situated thought", that is in finding a connection between the test's quizzes and their cognitive abilities. In addition, children must learn to implement situated meta-cognitive strategies, i.e. they should be able to recognize cognitive resources required by a task as previously faced in other tasks.

Starting from our observations, we designed coding laboratories, taking into account that the problem of *"representation"* is the central issue for children to solve problems.

3.2 Phase 1

Scratch allowed learners to separate the essentials of a problem from the narrative, presenting the question visually. In this way, students could overcome the fear when reading a "narrative" problem and their performance, as measured on selected INVALSI quizzes, improved of about the 40%. In addition, by joining the community of Scratch, teachers, and learners could share their experience. This latter possibility increases the children's motivation and helps them to develop group cooperation attitudes, allowing them to achieve better results. Challenges become an integral part of learning.

The gaming approach allowed children to overcome any fear about the INVALSI test. In two weeks, they started to "decode" on their own the information given by the quizzes, thanks to the abilities acquired conding (not only logic and problem-solving approach to mathematical and scientific problems in general, but also visual-spatial abilities).

The activities involving the use of the Lego Mindstorm kit also addressed significant considerations. Considering the young age of the students and that the teachers were not expert in coding, the visual programming tool (EVE) included in the kit represented a convenient choice. Moreover, the visual approach also recalled Scratch to students, allowing them to feel confident also in programming a robot.

Creating a robot from scratch allowed learners to make concrete the scientific subjects, which lose their abstract characteristic. Algorithmic thinking and problem solving, indeed, are naturally part of the learning skill needed to design and develop both the robots' hardware (the physical appearance) and the software procedures (the actions, made possible by visual programming block).

In the activities made with the Lego Mindstorm kit, there has been no direct connection with the INVALSI's quizzes, because no problem could be directly translated in robotics. Moreover, all the activities performed with the robotics kit have been helpful to acquire and consolidate visual-spatial abilities and the problem-solving approach. Indeed, since EVE is a visual programming environment, structuring robots' actions such as movements helped students to develop and empower their visual-spatial skills. In addition, the physical realization of a robot, made of Lego bricks, allowed students to design the solution, before realizing the physical object. This could reinforce both the problem-solving approach and the visual-spatial skills and the ability to predict the effectiveness of the final realization.

3.3 Phase 2

The Phase 2 of our project consisted in a preliminary test of the coding and gamification approach and outcomes collection is still *in fieri*. During this preliminary stage we obtained some interesting results by using BCIs. Indeed, in the first attempts to succeed in the games provided with the Neurosky headset, only the 30% of the students were able to pilot the characters of the games through the required task, because they were distracted by their schoolmates or not able to really focus on the objective of the game itself. After three lessons, 100% of students learned how to concentrate on the game goal. We registered, also, the improvement of their ability to focus. At the beginning the 30% of the students was able to achieve a 70% of attention (relatively to the visual bar proposed by the games) and the remaining 70% was in the interval 20-40% of focus. After three lessons, the 87% of the students was able to achieve a 80% and the remaining 13% was in the range of 55-79%.

4 CONCLUSIONS

The project gave us interesting hints. The differences between the two involved classes allowed the development of dynamics able to support the children's personal development.

We registered homogeneous performances in both the classes. This means that the interdisciplinary and cooperative work made by the teachers allowed to reciprocally potentiate, facilitating learning path whose result will be evident in a very short time. Targeting personal empowerment and not only to acquire specific skills allowed children to go deepen in personal excellences arisen from the project.

In education, gamification is a powerful mean, allowing propagation of learning, development, and dissemination of knowledge. This is achieved by involving children in creating games and problems, using reality as a testing ground, in our specific case also including mathematics, and in it, dealing with INVALSI Tests (Dicheva et al., 2015).

All the classes and the laboratories implemented were based on gamification (Hamari et al., 2014) and we observed the following outcomes:

- produced immediate feedback
- allowed the repetition of activities
- aroused intrinsic motivation
- provided a multidisciplinary perspective
- gave the possibility of a future self-replication

These gamification characteristics reduce anxiety and boredom and provide positive emotion in learning, letting students replicate the self-learning process (Csikszentmihalyi, 2014).

The "apparent passivity" of teachers pushed children searching for autonomous solutions, trying and learning from their own mistakes thus developing a problem-solving-oriented approach. (Gardner and Davis, 2013). The "try and error" method helps children to reduce "test and evaluation anxiety" and to increase their curiosity (Montessori, 2008; Munari, 2004).

This case study highlighted that the construction of educational tools and processes based on the gamification and integration of different disciplines favour the harmonious growth of the individual. The application of gamification to education enables rapid and harmonious development of self-awareness, self-adaptation and self-learning. Due to its success, the project followed up, and teachers and students have been involved in even more complex coding activities.

We argue that the key of gamification consists in enhancing our natural attitude to approach real problems. In a next step, we'll increase the difficulties children will have to face, just like when playing games, also involving students in a game design.

The students involved in the present study are currently in the fifth class of Primary School and we are waiting the results of the INVALSI test that will take place in June 2019. The original group of pupils is working well in math and the students show even more autonomy. They are currently taking part to the Transalpine Mathematical Rally (http://www.armtint.org/index.php) and to The Computer Science Bebras (https://www.bebras.it/).

The last simulation (February 2019) made by these student (now aged 10) were satisfactory and, above all, the students in difficulty have performed very well.

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