A digital platform for teaching mathematics

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ABSTRACT

In this paper, we present a complete platform for an innovative way to teach mathematics. The platform is composed of a serious game to help children to understand fractions, and a web portal that allows teachers to configure exercises involving fractions, but also to design completely new exercises using a very simple block-based programming language. In this way our tool can be used by primary school teachers as an help to teach mathematics, but also secondary or high schools teachers to teach students computational thinking and basic skills of programming languages.

CCS CONCEPTS

• **Applied computing → E-learning**.

KEYWORDS

Serious Games, Mobile Applications, Teaching Mathematics, Block-based language

1 INTRODUCTION

Mathematics is often a hard subject for children, which often encountered difficulties in its understanding. Pupils usually consider exercises, and in particular homework, boring and strenuous activities. Some studies, among which [14], have shown that children prefer to learn from pictures, sounds and videos, instead of paper and books.

Although many teachers do not like the idea of using video games in their classrooms, Mayo [15] demonstrated that using *serious games*, i. e., games that hide under a game activity a *serious* goal, e.g., teaching mathematics, increased pupils' achievements from 7% to 40% as measured by standardized testing including high school algebra and college-level numerical methods. Moreover, Young et al. [21] found some evidences of positive effects of the use of serious games not only on learning of this topic, but also on language, history and physical education.

These findings show that the use of technological tools in teaching mathematics to children gives interesting results. The problem is how to design and develop effective tools. According to Paul Drijvers[2], the crucial factors for the success of using digital technology in teaching math are:

(1) the design of the digital tool, in terms of functionalities but also of pedagogical and didactic background in which the tool is incorporated,
(2) the role of the teacher, that should orchestrate learning, alone or collaborating with other educators, and
(3) finally, the educational context in which the technology is embedded, that should be coherent and integrated in a natural way with the technology itself.

Starting from this consideration and taking into account that many tools are thought to be used at home by the children themselves and not in classroom guided by the teacher, we developed an integrated platform both for children and teacher. In particular, we wanted to give more freedom to the teacher, who can have the possibility to create her/his own exercises.

This choice is appropriated according to (1), because we are going to provide a new perspective, a new approach to the topic of "create exercise", as we want the teacher to be free to design possibly every kind of new exercise he/she wants, where by "new exercise" we do not mean a new instance with new parameters of a particular kind of exercise, but a completely new *type* of exercise. In fact most of the platforms that enable the creation of exercises nowadays allow only to select a type of exercise from a list, usually containing questionnaires, forms with multiple choice, textual questions and answers, and other few models of question.

This choice supports also points (2) and (3) highlighted by Drijvers, because the teacher is naturally an orchestrator

as the creation of the exercise is his/her own task, and the teacher comes into play in explaining concepts that are not self-evident. Also, the exercise could be created in the context and in the way he/she think it is useful, thanks to the high level of freedom allowed by our platform.

Suppose as an example, that the teacher wants to show the operation 5 x 3; two possible ways to teach how the multiplication works in the primary school are using grouping or formation. In the first approach, the objects of multiplications are drawn and then grouped, drawing three circles, i.e., groups, of five elements. In the second approach, the objects of multiplication are disposed in three lines of five objects. During the lesson the teacher can choose between one of these approach, and he/she probably wants that the students use the same representation of the multiplication when solving the proposed exercises. Using this kind of platform the teacher can design the multiplication exercise in a coherent way with what he/she has illustrated during lessons and do not have to adapt to the approach used by the tool.

In this paper, we present a complete platform for an innovative way to teach mathematics. The platform is composed of a mobile app, *"Pizza al Lancio"*, a serious game for the children to help them to understand fractions, and a web portal for teachers, to allows the configuration of exercises involving the fractions, but also to design completely new exercises. The serious games was already presented in [4] but it did not allowed any configuration. In this paper we extend the previous app and integrate it in the new platform.

The web portal for teachers uses a very simple programming language based on visual blocks that can be used as brick to program (build) the exercises. In this way our tool can be used by teachers from the primary school as an help to teach mathematics, but also by teachers from secondary or high schools to teach students computational thinking and basic skills of programming languages.

2 RELATED WORK

Many works in literature addressed the problem of using technological tool to improve teaching. Kaput et al[8] states that electronic media are interactive, which means that a student's action yields a reaction on the part of the machine, which in turn sets the stage for interpretation, reflection, and further action on the part of the student. Without this kind of interaction, the only interactivity possible involved another human reacting to what the student produces, so, technologies are reinforcing the pedagogical shift to active learning. The authors also highlight that many technologies outrun the activity-boundaries of its initial design, and a solution for this problem could be that the teacher designs her own material inside the implicit boundaries that there are in a school.

Guskey [6] provides some guiding principles to stimulate a teacher to adopt technology in teaching mathematics. Some of them are the insurance that teachers receive regular feedback on students learning and the importance of collaborative work with colleagues teacher. Thanks to this observation we have already added a page that reports students learning outcomes and we want in a future to add some features of collaboration between teachers. This regular feedback for the teacher, according to Rogers [19] triggers a virtuous circle for which student learning outcomes changes the teacher's classroom practices, that in turn changes the student learning outcomes and so on.

Farrell [16] and Makar [11] share the Guskey view about a major level of activity from student, stating that technology can change the nature of teaching mathematics by engaging students in more active mathematical practices such as experimenting, investigating and problem solving that bring depth to their learning and encourage them to ask questions rather than only looking for answers.

Gomez-Zermeno et al [5] states that the use of virtual platforms can be very helpful if teachers use it from planning their classes and as an ally in the pursuit of the objectives and goals of math education.

Another issue that Kaput [8] noticed is that many tools are designed by people steeped in the technology but without deep insight into the problems of mathematics teachers. We solve this problem acting on two fronts. Firstly we want to involve math primary teacher in our design and testing activities. Secondly, we want the teacher to be at the center of this technological and didactic process: nowadays a new generation of programming tools is available and they make programming more accessible to everyone [13], also for teachers that can be able to design and create code about his/her didactic material. For example, Malan [12] proposed Scratch[1] as a first language for first-time programmers in introductory courses, for majors and non-majors alike. There are studies that confirm this effectiveness of this kind of tools in teachers community too as Cetin affirms [1].

From a practical point of view, many works in the literature support the use of technology to support learning. Google classroom[2] is a platform where teachers can share with students documents and medias, create simple assignments and give feedback to students' work. Shaharanee et al [17] stated that the majority of the students is satisfied by the Google Classroom tool that were introduced in their class. In particular the authors noticed its ease of access, perceived usefulness, communication and interaction, instruction delivery and students' satisfaction towards the Google Classroom's active learning activities.

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[1]Scratch web site: scratch.mit.edu
[2]Google Classroom web site: classroom.google.com

Other works address the integration of game in teaching mathematics. Katmada et al [9], for instance, present an online game named "Volcanic Riddles", in which children has to solve mathematical puzzles to escape from an island where a volcano is going to erupt. The game was used by primary and secondary school students and was really appreciated. ""Messenger Quest" [7] is a game thought for Millenials to teach them maths competencies and mathematical thinking. The game practices measuring tools, weight distribution, estimation skills and fractions. Other works are more specific and address the problem of teaching fractions using computers or mobile games [10, 18, 20].

3 DESCRIPTION OF THE PLATFORM

We developed an educational platform composed of a website and a cross-platform application. The website is supposed to be used by a primary school teacher to create exercises that will be sent to students, who solved them through *PizzaAl-Lancio*, the smartphones/tablets application.

The main idea behind this project, and in particular behind the website, is to guide a teacher during the process of creation, assignment and management of teaching materials, through various phases providing more freedom.

In the first phase, the teacher assigns the math exercises concerning fractions with randomized data input. This is the phase that requires less effort from the teacher, but also the one that gives him/her less freedom, as the data and the rules that make the game works are chosen in an automatic way by the platform. For this reason, in this phase the teacher does not need to use the website. The kinds of exercise that can be assigned to the students in this phase concern only fractions. This phase was tested in an Italian school with good results [4].

In the second phase, the teacher establishes the data input using a specific page of the website, the *Numeric Values* page. With this approach the teacher can decide the value of the numerators and the denominators for these exercises. He or she need to care neither about the design of the game/exercise interface that is displayed in the application, nor about the rules that make the game work. Even for this phase, the only kinds of exercise that can be assigned to the students concern only fractions.

Instead, in the third phase, the teacher creates his/her own exercises, using the *Exercise Creation* page. With this approach he/she can design the game interface composing graphic objects as he/she wants in the most effective way to promote learning of the topic at hand. After that, the teacher can provide the rules that makes the game works. Some examples are: the definition of which objects can be clicked or moved by the student, the appearance and disappearance of texts after that some actions are carried out, the definition of what should happen after a student has chosen either the

Figure 1: Racing scooters animation: each motor-scooter represents a student's score, as the name on the left of the scooter suggests. The final position of each scooter depends on the student's mark.

correct or the wrong answer and the scores management. Since the process of creating digital exercises is a complex task due to a high degree of freedom, ad-hoc instruments have been used to facilitate the learning curve.

Besides the already described functionalities, the website also contains:

- a *Login* page, that allows the teacher to log into the platform,
- the *Exercises* page which provides a dashboard, that can be used to view, edit and delete previously created exercises and
- the *Race* page which reports students' exercises results using an animated motor-scooters race to represent them: in Figure 1 each scooter represents a student's score, as the name on the left of the it suggests. Initially, all the motor-scooters are on the same position on the left or the road, then they starts moving. The final position of each scooter depends on the student's mark. Thanks to this animation, the teacher can show the results to students in a funny way to make learning more attractive.

Exercise Creation Page

The core of this platform, that defines its novelty, is the *Exercise Creation* page (see Figure 2). It is clearly divided in two columns: the canvas (on the right) and the toolbox (on the left). Using the canvas on the right, the teacher can insert and style graphical elements of the exercises, such as shapes, text, images, and numbers. These objects can be styled in different ways, and can be placed as background or inside questions and answers that the teacher wants to create.

On the left, there is a toolbox where the teacher can define the behaviour of the exercise, using a block-based programming language. For example, the teacher can set which elements the students can interact with, the correct sequence of
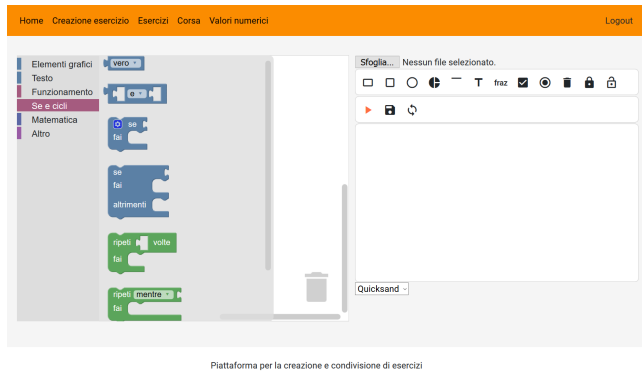
Figure 2: Exercise Creation Page: the canvas on the right is used to design the interface of the exercises while the toolbox on the left is used to code their behaviour. The platform is developed using the Italian language to be used by the Italian teachers.

phases that the students should execute, the rules by which display congratulations, accumulate and show scores.

To model the behaviour of the exercises, in a simple and effective way, we introduced a high-level block-based programming language, that contains special blocks, inspired by other block-based programming language like Scratch, that can be composed to easily interact with the graphical objects inserted in the canvas on the right.

To provide immediate testing of the exercises defined, even during the creation process itself, we introduced a real-time run mode, activated by a *play* button. This mode simulates the execution of the exercise in the canvas as it will appear to students, with all the objects, the rules and the behaviour composed by the teacher through the toolbox and the canvas.

Technical implementation

The platform is mainly implemented using a *MEAN (i.e., MongoDB, Express, Angular, Node.js)* [3] stack, which guarantees a scalable fullstack JavaScript application, starting from the top (code running in the browser of a client) to the bottom (database and application logic that run on a server). The MEAN stack is composed of:

- **MongoDB**[3]: non-relational database that stores data used by the application in JSON format. Each JSON file is an encoding of an exercise created by the teacher.
- **Express**[4]: a back-end web application framework running on top of Node.js;
- **Angular**[5]: formerly Angular.js - front-end web app framework that runs JavaScript code in the user's browser and

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[3]MongoDB web site: mongodb.com
[4]Express web site: expressjs.com
[5]Angular web site: angular.io

- **Node.js**[6]: JavaScript runtime environment on which the application runs.

The logical flow starts with the user (the teacher) that interacts through the browser to create an exercise. Then the exercise is coded in a JSON format and a POST HTTP request is sent to the server. Express receives this request and manages it, saving the JSON file in MongoDB.

Focusing on the Angular front-end, other front-end libraries were used to develop the Exercise Creation Page. In particular:

- **Fabric.js** [7] is used to create the canvas for the design of the interface of the exercises. It is a powerful HTML5 canvas library that has been chosen because it offers many low-level functions such as managing images, shapes, texts, animations, events and drag-and-drop functions that are useful to facilitate the development of the canvas and
- **Blockly** [8] is used to create the toolbox for the design of the behavior of the exercises. It is a JavaScript library for building visual programming editors. Blockly is used by hundreds of projects, most of them educational, e. g., AppInventor [9] or Microsoft Make Code suite [10], which offers also an extension for Minecraft [11].

Blockly offers a suite of standard self-contained blocks representing coding concepts. It outputs syntactically correct code in the programming language chosen, Javascript in our case, and possibly every line of Javascript code can be written composing blocks. It also allows the developer to create his/her own blocks. These blocks can be dragged-and-dropped in order to build scripts in graphical way. Then, the scripts generate the JavaScript code that describes the logic of the exercise.

Blocks are logically divided into five categories, i.e.:

- the graphical elements category, containing a custom block for each element inserted in the interface of the exercises and blocks to customize them;
- the text category, for string management;
- the operations category, containing custom blocks to manage events and actions performed in the interface, such as the block to show an element, the block to reach to a click on an element, and others;
- the logic and loop category, containing the boolean variable true-false, if-do block, if-then-else block, the equal and different operators, the less/greater than

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[6]Node.js web site: nodejs.org/en
[7]Fabric.js web site: fabricjs.com
[8]Blockly web site: developers.google.com/blockly
[9]App inventor web site: appinventor.mit.edu
[10]Microsoft Make Code web site: microsoft.com/en-us/makecode
[11]Minecraft web site: minecraft.makecode.com

Figure 3: Exercise interface after the student has clicked on the square. This script is composed using the toolbox of the Exercise Creation Page. The string *"Ben fatto!"* means "Well done!" in Italian.

operators, the repeat n times block, the while block and others and

- the math category, containing blocks as the numeric variable block, the sum block, difference, multiplication, round, even, square root and so on.

The blocks mentioned in the first and in the third category are ad-hoc created for our platform, in order to connect the interface of an exercise to its behaviour.

This technological stack is used to develop the creation of completely new exercise. The personalization of the exercises on fractions of the app *PizzaAlLancio* is performed through the use of a web form that the teacher has to fill in and required the development of three services:

- a service that receives and stores the input data (numerators and denominators) established by the teacher using the web form;
- a service that receives the performance results of the test;
- a service that shows the performance result of the test using the animation of the race scooters.

In order to guarantee backward-compatibility with the previous Corona Application developed for the randomized fraction exercises, these services are developed using an Apache web server on which PHP runs in order to manage requests and store data in a MySQL database.

Use case

To clarify the process of creating an exercise, we explain a very simple concrete use case, step by step. Let's suppose that a math teacher is explaining the geometrical shapes to her/his class. He/she wants the students to recognize different shapes such as, square, rectangle and circles. Using our platform he/she can create exercises that asks students to recognize a particular shape between others. The student is required
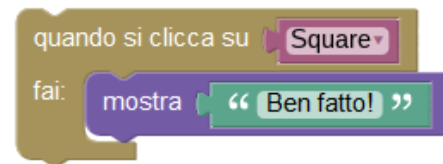

Figure 4: The script that models the behaviour of the exercise. We used the Italian language since the system is used in Italy.

to tap the correct shape. So a question could be: *"Tap on the square"*, where the possible answers are all the shapes but only the square is the right one.

To create this exercise the teacher must insert in the canvas on the right the text *"Tap on the square"*, using the button "T" that stands for "text", and then he/she can insert the shapes he/she wants, e.g, a square, a circle and a rectangle. To have a better design of the interface, the teacher can also insert some background or other graphical objects. All objects can be moved or deleted.

At this point, the interface of the exercise is created, and the teacher has to model the behaviour of the exercise: what happens if the student tap the right shape. The teacher decides to shows the string *"Ben fatto!"* (i. e., well done in Italian) when the child clicks on the square, so he/she adds this string in the canvas. The result is shown in Figure 3.

Next step is to model the behaviour of the exercise using the toolbox on the left in Figure 2: when the child clicks on the square, the string *"Ben fatto!"* must be displayed on the interface; nothing happens in case of wrong answers. The teacher can model this behaviour by composing the correct blocks.

Figure 4 depicted the composition of blocks needed to obtain the described behaviour (in Italian). The block "Quando si clicca su _ fai" ("When _ is clicked do" in Italian) belongs to operations blocks and reacts when an object is clicked. The object is identify by the block "Square". The block "Mostra _", i.e., "Show _" displays the string "Ben fatto!". The teacher also needs to define a block belonging to the category of graphical elements displayed in the interface. The composition shown in Figure 3 was obtained using drag-and-drop.

This simple example can be extended to other topics of mathematics. Some example of extensions can be:

- exercises for angles: ask the student to denote, using a pen instrument, all the acute angle among many angles graphically proposed;
- exercises for fractions: ask the student to sort fractions numerically represented by drag-and-drop;
- exercises for multiplications: ask student to draw, using a stencil instrument, a multiplications using the

graphical grouping way (for example "6 * 3", draw 6 circles inside three predefined circles;
- exercises for properties of mathematical operations (e.g., commutative, associative): ask the student to apply some distributive property to operations using arrows.

4 CONCLUSIONS

In this paper, we proposed an integrated platform for teaching mathematics. We extend a mobile serious games on fractions, *PizzaAlLancio*, to allow teachers to have personalized exercises for their students. The new platform adds two new functionalities: (1) the possibility to decide which fraction is presented to the child, asking what the complementary/equal fraction is, and which are the possible answers displayed and, (2) the possibility to design completely new exercises.

However, this second functionality gives the teacher a higher level of freedom. Thinking to a school growing in the perspective of customization, it would be possible to create different exercises and assign them according to the specific needs of the students.

The teachers implement the behaviour of the exercises using a very simple block-based programming language, which has high expressiveness. For this reason, the teacher's interface can be used not only by the teachers for the design of math exercises for children of the primary schools, but also to teach computational thinking and basic programming skills to students of secondary and high schools.

Finally, as an extension, if students had also access to the platform, they could be coupled and, in turn, a student either creates an exercise or resolves the exercise created by the schoolmate. This could stimulate cooperation within a classroom learning math, thanks to the exercises, but also training creative thinking, computational abilities and making coding applied to mathematics. We plan to investigate all these possibilities in our future works.

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