Eating Pizza to learn fractions

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ABSTRACT

Mathematics is often a hard subject for children, especially because they are usually not able to perceive any concrete connection between math and the real world. There is a rift between what they do for fun ad what they are required to do at school. This is partially due to the concrete aspects of the activities they do in those two contexts, which are inherently different of course. But it is also due to a deep difference in the means which are used since children prefer to learn from pictures, sounds and videos, as some recent studies have shown. For this reason, we implemented *"Pizza al Lancio"*, a serious game to help children understand fractions, in particular *equivalent* and *complementary* fractions. The game tells the story of a hungry delivery boy who happens to eat some slice of pizza while transporting it, and so he asks the player for help in order to avoid delivering incomplete pizzas. The game has been tested with two groups of primary school pupils.

CCS CONCEPTS

• **Applied computing → E-learning**;

KEYWORDS

Serious Games, Mobile Applications, Teaching Mathematics

ACM Reference Format:
Ombretta Gaggi, Francesco Ciraulo and Marco Casagrande. 2018. Eating Pizza to learn fractions. In *International Conference on Smart Objects and Technologies for Social Good (Goodtechs '18), November 28–30, 2018, Bologna, Italy*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3284869.3284921

1 INTRODUCTION

Since the introduction of the first graphic interfaces, video games have kept generations of teenagers fixed on the screen. This situation has worsened with the advent of mobile phones, which are now so pervasive that they occupy almost all young people's spare time. And games have a big part in this.

But games can also become a big opportunity, because when people have fun, then they are more willing to do what they have to. *Serious games* respond to this issue: they hide under a game activity what the user usually finds boring although useful, for example rehabilitation exercises, school work, and so on.

Homework, and school assignment in general, are often considered strenuous and boring activities. According to Forman [5], children think that math is an arid subject without much connection with the real world, apart from the fact that it is needed for accessing university, a very long-term goal from the point of view of a primary school student. Stodolsky et al. [17] showed that the main reason for this negative opinion is frustration, the sense of failure due to the difficulties pupils experience in studying math. There seems to be a rift between what children do for fun and what they are required to do at school [8]. Moreover, some studies (among which [13]) revealed that Millenials have preference to learn from pictures, sounds and videos, as opposite to texts. For these reasons, *serious games* can be a solution: they can be used to improve the quality of teaching, especially of difficult subjects like math, to attract the user's attention, and to propose new strategies for solving exercises.

Even if *serious games* cannot wholly replace traditional activities, many studies have shown good results in lowering the drop-out-from-therapy phenomenon [1, 7] and in improving rehabilitation therapies [3, 4, 6]. Learning games may be associated with formal education environments. Although many teachers do not like the idea of using video games in their classrooms, Mayo [14] demonstrated that using such games 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 on language learning, history and physical education.

In this paper, we present *"Pizza al Lancio"*, a serious game to help children understand fractions, in particular, *equivalent* and *complementary* fractions. The story underlying the game tells about an hungry delivery boy who eats slices of pizza during its transportation. Since he cannot deliver incomplete pizzas to the customers, he asks the player to launch[1] the piece, i.e. the complementary fraction, which completes his pizza. The use of a pizza allows us to connect an abstract concept, namely that of a fraction, with a concrete experience: according to Peters [11] this is one of the keys to success in teaching.

The paper is organized as follows. Section 2 describes the related works in the literature. Section 3 describes the game, its levels and tutorials, its implementation details, and presents some pedagogical considerations. Results obtained by a user study performed in an Italian primary school are presented in Section 4. Finally, we conclude in Section 5.

Goodtechs '18, November 28–30, 2018, Bologna, Italy

ACM ISBN 978-1-4503-6581-9/18/11...$15.00
https://doi.org/10.1145/3284869.3284921

[1]The name *"Pizza al Lancio"* comes from the operation to "launch" the pizzas, in Italian "lanciare".

Figure 1: Example of a question to the player: in this case the player must throw the complementary fraction (in Italian "Completa" means "Complete").

Figure 2: Interface for the choice of the chef (in Italian "Scegli il tuo chef" means "Choose your chef").

2 RELATED WORK

Other works in the literature address the problem of teaching mathematics to children. Many of them propose game to support learning in 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: the results suggest that game-based learning activity are appreciated by the students and so they can be easily integrated into the classroom to support teaching of mathematics.

"Messenger Quest" [8] is a game thought for Millenials to teach them maths competencies and mathematical thinking. The user has to help a friend to deliver a letter to the queen. But the letter was broken into a thousand pieces, and to find all of them, the user has to answer mathematical puzzles. The game practices measuring tools, weight distribution, estimation skills and fractions. This game has also the goal to positively impact attributes towards maths.

Other works are more specific and address the problem of teaching fractions. Some authors propose games based on the use of pencil and paper [2, 16, 18]. In this paper, we will focus on works considering pc-games or mobile games. In [15], Norton et al propose a mobile app to develop students' partitioning capacity. Students are required to partition a candy and to show the part which corresponds to a given fraction. The task is more complex for *improper* fractions which represent parts bigger than the whole.

"Monkey Tales: The Museum of Anything" [19, 20] is an educational pc-game used to practice mathematics. This game belong to the category of adventure games, but it contains also some elements of action games (e. g., shooting to bubbles with fraction which represents the right answer). Players has to defeat the huge dinosaur Carmen Pranquill that has taken over the museum by solving more quickly maths puzzles like comparisons or operations with fractions.

Lee [12] describes the use of a digital game to support learning of sorting a set of fractions. Each fraction is represented as a vertical or horizontal wooden brick. The brick has a fraction represented inside or can be divided into fractions according to the level of the game. The results recorded by comparing pre-tests and post-tests show that the impact of the game is minimal in the sorting capability, but the game has enhanced students' understanding of representation of fraction in rectangular divided quantity diagrams.

Most of the approaches described so far, implemented pc games or web games but not mobile applications specific for learning of fraction. Kearney et Maher [10] instead have shown that iPads are very efficient tools to help teachers to prepare learning material.

Some mobile applications exist in the markets, but they usually focus on operations and are not fully integrated in the learning process in the classroom: e. g., Fractionstodecimals in the Apple Store focuses on the conversion of fractions to decimals. Moreover, the final outcomes of these apps have not been studied.

3 DESCRIPTION OF THE GAME

"Pizza al Lancio" is an educational game for smartphones and tablet. As already discussed in Section 1, the game tells the story of a delivery boy, who is hungry and eats a portion of pizza during the delivery. Since he is scared by his severe boss, who shouts at him if the clients are not happy, when he arrives at the destination he rings to the player, asking his/her help to complete the pizza. The player must throw him the correct box, among the four available, i. e., the one containing the complementary fraction to the delivered pizza, thus fulfilling the current customer's order.

Figure 1 shows the delivery boy waiting for the player action. The bar on the top shows the number of correct answers, denoted by a green tick, the number of incorrect answers, denoted by a red cross, and the number of questions to complete the session. The game has been implemented in Italian since it was tested in an Italian school.

At the beginning of the game, the player can choose between four helping chefs (see Figure 2): they will be giving instructions and comments at each level (the choice of the chef is irrelevant for the development of the game: it is merely for aesthetic reason). Then the player can choose between eight different levels: the first half helps to understand complementary fractions, the second half deals with equivalent fractions.

The first and the fifth levels are not real levels but act as tutorials, respectively for complementary and equivalent fractions. Therefore the real levels are only 6, from 1 to 3 deals with complementary fractions, levels 4 and 5 deals with equivalent fractions. Level 6 asks a complementary fraction, but the possible answers do not have the same denominator, so children must have learned both equivalent and complementary fractions to complete this last session.

Upon entering the first tutorial, a brief explanation about the story is shown, then the tutorial shows the gestures to throw the pizza, and asks the player to repeat them. Some examples of question are proposed to the player for training, letting the kids get accustomed to the game and its interface. In the same way, the second tutorial introduces equivalent fractions.

The real challenge begins with level 1, which introduces fractions with 6 as denominator. The second level is more difficult because fractions are represented by pizzas with non-adjacent slices. The third level sets a 10 seconds time limit for the delivery, using all of the elements previously introduced. The fourth level deals with simple equivalent fractions while the fifth level challenges the player offering non-adjacent versions of fractions and a wider variety (denominator = 12). Level 6 asks the kids to combine elements from both complementary and equivalent fractions.

The alternatives among which the player has to choose are represented as pizza boxes which bear both a symbolic representation of a fraction (i. e., numerator / denominator) and a visual representation by means of pizza slices (see Figure 1). Possible denominators are 2, 3, 4, 6, 8 and 12. Any numerator is possible if not exceeding the denominator (e. g., if the denominator is equal to 6, the numerator ranges from 1 to 5). We made this choice to enforce the relationship with reality, where each box contains only one pizza; for this reason we represent only proper fractions. Improper fractions are shown only as a response to a wrong answer by the player, namely when he/she chooses a too big piece of pizza.

There are three different versions for each fraction, with the slices all attached to each other (see 5/6 in Figure 1) or scattered in the box (see 2/6 in Figure 1), to increase difficulty and create more variety.

If the player gives an incorrect answer, the game explains the mistake (Figure 3): the game shows the operation obtained with the chosen box and its result. In this way the player can understand if he/she has chosen a too big or to small fraction.

When the last pizza is delivered the session ends evaluating the player's pizza-delivery service. The game summarizes the number of correct deliveries and the time spent. It also tries to mimic a real customer review which depends on the number of correct answers. The idea is to push the player to perform better and really try to appeal to customers with a good performance. Reviewers and customers' comments are chosen randomly, at the same performance, from a preset pool where comments are categorized as bad, good or perfect.

3.1 User interaction

Since the game is intended for primary school children, we designed a very simple user interface: we used really basic gestures, i.e., "tap" to navigate the menus and "drag" to throw the pizzas to the bellboy. During a level, it is not possible to exit or pause the game. The idea is to make the child answer the question in a limited time interval: we want to avoid that the pause command can be used to have more time to answer the question. However, we must note here that the levels are extremely short, so we do not really block the child. Anyway, the bar on the top of the interface shows the current progress.

Players have two goals: to fulfill all orders correctly and, less important, to use the least amount of time. Both parameters are shown in the evaluation screen at the end of each level and influence the review being displayed.

3.2 Technical implementation

"Pizza al Lancio" was developed using a cross-platform development framework which allows one to develop the game once and then distribute it in both Android and Apple platform. Since we want to reach the largest number of users, this feature is very important for the project.

We used the framework Corona[2], a free 2D game engine supporting the Lua scripting language[3], a lightweight and simple, yet powerful language. Corona features APIs and plugins specifically tailored to create games and apps for mobile devices. It also provides a simulator for real-time testing of the developed application.

More in details, *"Pizza al Lancio"* is not simply a mobile application, but it is implemented by a system whose architecture contains three components:

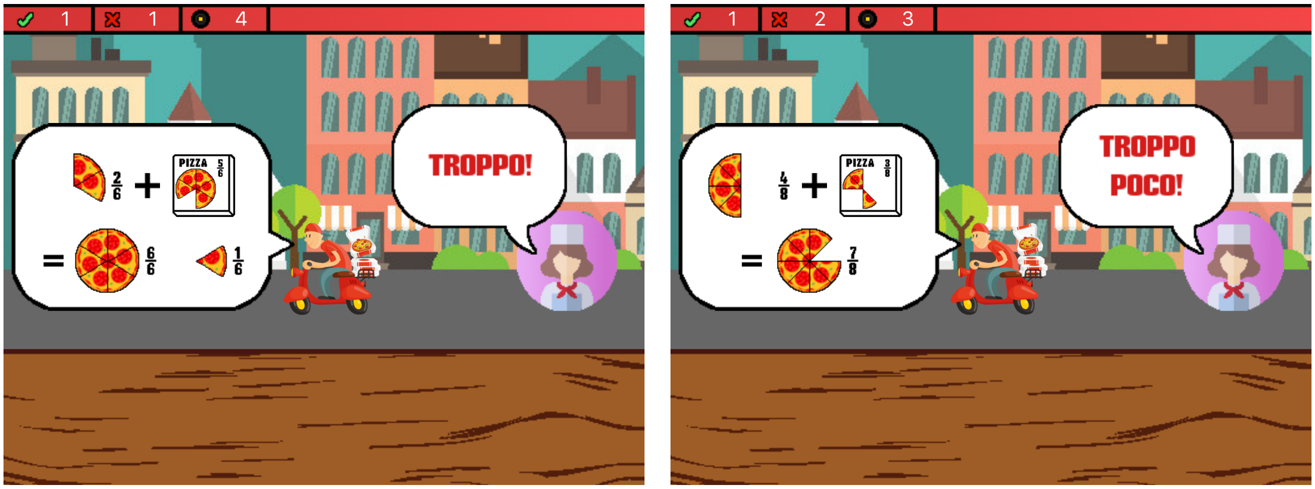
- the core application, i. e., the game;
- an online database storing data about the result of the game sessions. This data was collected anonymously;
- a service to send statistics from the application to the online database.

The core application is the game running on a smartphone or a tablet. The game is structured in scenes, using the composer library[4] that allows the developer to create and manage the scenes, acting as a director of the whole game. Each scene roughly implements a level or a screenshot (e.g., the initial menu, the chef menu, or the result page) defining its behavior during the playtime.

The sqlite3 library[5] was used to store information about game session in a local database. This data will be sent to the online database as soon as the smartphone is connected to a network. The use of the sqlite library allows to not block the game or lose data in absence of Internet connection.

Lua code files follow generically an object-oriented approach: every screen element is in fact an object. Level scenes have a standard structure based on a loop between phases. Correct behavior of the game was tested first by means of Corona Simulator and then directly on a number of smartphones and tablets (both on Android and iOS platform).

[2]https://coronalabs.com/
[3]https://www.lua.org/
[4]https://docs.coronalabs.com/api/library/composer/index.html
[5]https://docs.coronalabs.com/api/library/sqlite3/index.html



(a) (b)

Figure 3: Game responses when the player gives a incorrect answer: (a) the player chooses a too large fraction (in Italian "troppo" means "too much"); (b) the player chooses a too small fraction (in Italian "troppo poco" means "too few").

The game collects data about performance of the users. This data are collected anonymously and stored, for further analysis, in a database available through the Internet network. Since we do not have strong requirements, nor about data security (they are collected anonymously) nor about efficiency (it is very difficult that a huge number of kids play the game in the same moment), we chose a MySQL database. The database is very simple, only one table, holding the following informations about a single level playthrough:

- unique device identifier, to track each different device;
- session identifier, to track each new session started;
- correct answers, to track user performance;
- wrong answers, to track user performance;
- time, to track user performance;
- level, to track the level played by the user;
- date, to track the date of the level playthrough.

These parameters are used for evaluating possible pedagogical effects of our serious game. It should be noted that privacy constraints didn't allow us to gather more in-depth informations.

Data are sent using asynchronous HTTP request to URL identifying the server implemented with Corona's network library[6].

3.3 Pedagogical considerations

Our choice to use 8, 12 and their divisors as the only possible denominators for our fractions is motivated by several reasons. First, a practical one: we get six possible denominators (2, 3, 4, 6, 8, 12), hence a sufficiently large stock of examples for the game to take place unmonotonously. The second reason is cultural, in the sense that 8 and 12 are peculiar from both a mathematical and a historical point of view. The former is a quite recurrent number in our everyday life, like other small powers of 2, which comes out naturally when halving things repeatedly. Pizzas, for instance, are usually cut into 8 slices by halving three times. The number 12 is perhaps still more important in our culture. Its multiple $60 = 12 \times 5$ was chosen long time ago, at the origin of our civilization, by the people living in Mesopotamia. And their sexagesimal system is still visible in our way of measuring angles and time. So 8 and 12 are close to children's everyday experience . In this way pupils' activity during the game can be supported by their real-life experience and knowledge; this goes in the direction of promoting a fruitful interaction between out-of-school and in-school mathematical knowledge, a task which is not always pursued, and seldom fulfilled, at school. Clearly, using pizzas is an explicit reference to the real world already. However, noticing the analogy with other aspects of reality (such as clocks) can contribute to achieve one of the most important and general goal of maths education, namely, improving children's perception of the significance of Mathematics in their lives.[7]

4 TESTING THE GAME

After some homemade alpha testing to detect potential bugs, our app underwent a kind of 'beta' test to evaluate satisfaction rate by our prospective customers, namely students, and to start collecting data about the effectiveness of the game as a teaching tool. At the end of May 2018 we presented our game to two classes of a primary school in Italy. A total of 34 students participated in the study, 17 fourth graders and 17 fifth graders. We planned the experiment at the end of the school year in order to be sure that fourth graders had been working on complementary and equivalent fractions. The study was organized as follows.

- A paper-and-pencil test was administered to asses pupils' level in recognizing and representing complementary and equivalent fractions.

[6]https://docs.coronalabs.com/api/library/network/index.html

[7]It could be argued that noticing and studying analogies is one of the main characteristic of nowadays Mathematics, which is certainly more interested in "structures" rather than in "objects". (Traditional mathematics, on the contrary, is usually identified with the study of some particular objects only, namely, numbers and shapes.)

- Then each student was given a tablet (computer) with our game installed on; they were left free to play at will, once or more times per level. All scores were automatically recorded by our online database.
- After that, we asked students to express their satisfaction about the game.
- In addition, fourth graders had the opportunity to play again some days before the end of the school year (June 2018); then they underwent a second (computer-based) test on fractions.

The experiment took place in the students' usual learning environment, namely their respective classrooms, and under the supervision of their teachers.

As already said, the player of our game is asked to find complements of proper fractions (numerator less than denominator) and to recognize equivalent fractions. According to many regulations around the world, this is a skill pupils must possess before they exit primary school. The Italian *Indicazioni Nazionali*[8] published by the Ministry of Education in 2012 puts this kind of skill among the objectives to be pursued between the fourth and fifth grades. According to the national curriculum in England (September 2013),[9] recognizing equivalent fractions (and representing them visually by means of drawings and diagrams) is one of the statutory requirements for the year 4 program of study, although the study of fractions begins much earlier. A similar approach is suggested by the Common Core standards in the USA.[10] Other Countries have made different choices. The city-state of Singapore, for instance, whose pupils always occupy the higher positions in the international rankings, suggests to study equivalence of fractions already at the third grade.[11]

Following a well-established tradition, many Italian teachers work on complementary and equivalent fractions at the fourth grade. Accordingly, one of our aims was to make our game fine-tuned for fourth graders. And apparently we managed in doing so. Indeed, the simple satisfaction survey we conducted after the game session (see Figure 4) shows that 88% of the fourth graders strongly liked the game (higher rank in a five-level Likert scale), and the others said they liked it (level 4 in the Likert scale). As expected, fifth graders were less enthusiastic: only 69% of them liked the game very much (Likert level 5).[12]

An inverse pattern emerges when considering children's performance in the game. According to our statistics, the overall percentage of correct moves is 77% in the case of fourth graders, while it is 85% in the case of fifth graders. A closer look at the game database (see Figure 5) shows that fourth graders performance usually decreases faster than fifth graders performance as the game level increases.

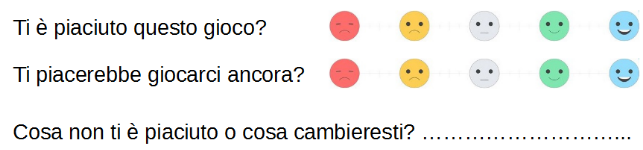


Figure 4: The satisfaction questionnaire ("Did you like the game?", "Would you like to play again?", "What didn't you like or what would you change?").

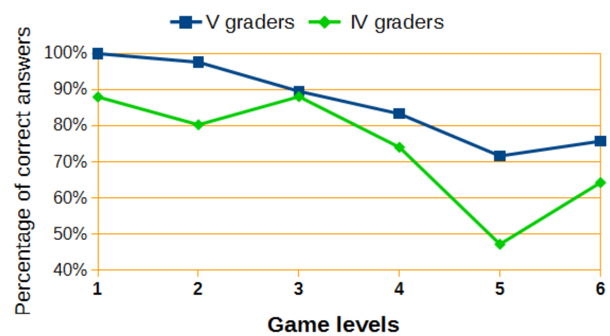


Figure 5: Children performance in the game

This confirms that the game is definitely too easy for pupils at the end of grade 5, while it is more likely to be effective for grade 4 (and, perhaps, at the beginning of grade 5). Further evidence for this last point is given by analyzing the results of the pre-test. The comparison between the outcomes of the two groups of students shows, once again, that fourth graders are still constructing some skills about fractions that are generally completely reached by their elder mates. On average, 67% of the items were answered correctly by fourth graders, while fifth graders reached 81%.

Therefore the case of fourth graders is the one that deserves a deeper analysis. A few weeks after the first trial, fourth graders played again as a part of their classroom activities. And our online database registered the event, of course. The statistics highlight an improvement in the fourth-graders' performance, which is now very close to the one obtained by the fifth graders a few weeks before. This is true, with one significant exception: the last level. In level 6, indeed, they performed slightly worse (-3%) than in their first attempt. Beating that level requires a combination of the two main skills needed for the game, namely recognizing complementary fractions and recognizing equivalent fractions. The question naturally arises as to whether a regular "consumption" of *Pizza al lancio* could have some positive effect for the development of such competencies.

Unfortunately, the comparison between the pre-test and the post-test administered in class 4 does not show a clear pattern: some children got a better score in the second test, some other not; on average, however, there was an increment of +3%.[13] Clearly, a

[8] http://www.indicazioninazionali.it/wp-content/uploads/2018/08/Indicazioni_Annali_Definitivo.pdf

[9] https://www.gov.uk/government/publications/national-curriculum-in-england-mathematics-programmes-of-study

[10] http://www.corestandards.org/Math/

[11] See the mathematics syllabus published by the Ministry of Education in 2012, p. 43 (https://www.moe.gov.sg/docs/default-source/document/education/syllabuses/sciences/files/primary_mathematics_syllabus_pri1_to_pri5.pdf). Notably such a syllabus suggests not to use denominators that exceed 12.

[12] Curiously, the two groups agree on the second question ("Would you like to play again?"): more than 70% of them mark the happiest emoticon. Parenthetically, the third question ("What didn't you like or what would you change?") too is of some interest: apart from the greatest majority of the pupils who answered "*Niente*" (Nothing), there were some who suggested to increase the number and difficulty of the levels-we shall take it under consideration for future developments of the game.

[13] The t-test gives a p-value of 23%.

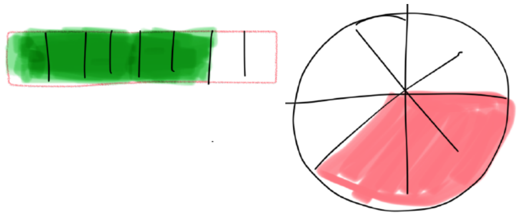


Figure 6: Two different ways (a 'bar' and a 'pizza') to represent fractions (original drawings by two 4-graders).

possible effect of the game would need a longer experiment (and a control group) to be evaluated properly. This issue is perhaps worth to be investigated further in the next future.

Nevertheless, perhaps unexpectedly, our app seems to affect pupils' way to conceive fractions. When asked to provide a visual representation of a fraction in the first paper test, almost all students decided to use a bar model (see Figure 6). Apparently, something had changed by the time of the second test (after playing the game): more than a fourth of the drawings are now pizzas! It is possible to conjecture that such a change is due to the influence of the game.

5 CONCLUSIONS

In this paper, we presented a serious game which is meant to be used as a teaching tool to help students understand complementary and equivalent fractions.

The initial tests carried out in an Italian primary school showed a good acceptance of the game, i.e., children liked to play the game and wanted to play again. Moreover, we did not need to provide any explanation to the children before the game session, therefore the game, both in its story and in its graphic, is correctly targeted.

Even if the tests lasted for a few days only, a too short time span to record any significant improvement in children's learning, our post-tests have shown that the game is able to influence the graphical representation used by the children to depict fraction.

For these reasons, we argue that a more intensive and extensive use of the game can support the teaching and learning of fractions at primary school.

Future works will be devoted to add new levels of difficulty to the game, to involve teachers in the design process of the game and of the levels, and to implement a long-term testing of the game.

ACKNOWLEDGEMENTS

The authors would like to thank all students and teachers of the primary school "Giovanni Pascoli" of Marsan, a hamlet of Marostica in the province of Vicenza, for their help and kind hospitality. A special thanks go to the fourth and fifth graders for testing our app, and to teacher Giorgia for her support.

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