The SmartGame: mixing digital and tangible to foster math education and social interaction

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ABSTRACT

In the current Work in Progress we present the SmartGame, a gamified web-app designed to support children in learning math and connected to an already existing tangible IOT device called SMARTER. Through introducing a cooperative modality and the union of digital and tangible advancements in technology, we also aim to foster interpersonal relationships in children from primary school, who suffered a lack of social interactions in person due to the recent pandemic. In the current project, we will study different possibilities of cooperation within the SmartGame, along with the ways in which teachers can personalize the activities and the gamification design based on students' needs. Finally, we will test the web-app usability, user experience, effectiveness in supporting students' education, and outcomes in fostering interpersonal relationships.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; • **Applied computing → Collaborative learning**.

KEYWORDS

IOT, Gamification, Education, Cooperation

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1 INTRODUCTION

In recent years Covid-19 pandemic challenged children's ability to cooperate and develop healthy interpersonal relationships. Schools were closed, and for many months, children could not socialize in person. Given the importance that the building of social relationships has on children's development [8, 11, 26], researchers all over the world tried to find new solutions to keep children in contact with each other [5, 23, 46] and different digital solutions were developed to help children cooperate in the educational setting [36, 45]. Nevertheless, now that students are back to school, it is important to support the building of new social relationships in person. On this matter, tangible tools can be useful in helping children to develop social relationships [44]. Tangible smart devices (e.g., Internet of Things – IOT) are proving their effectiveness in supporting different aspects of teaching and learning. They represent an interactive and engaging environment for students, giving them the opportunity to build their knowledge [1, 19, 37]. Furthermore, they offer the possibility to personalize curricula, based on children's ability [38], becoming suitable for specific learning disorders [9]. In order to take advantage of digital development, and integrate the benefits of a tangible tool, we decided to extend SMARTER [4], a tangible tool designed to support children in primary school in learning math, through the introduction of the SmartGame, a gamified web-app for elementary school children (6-11 years old). Gamification, in fact, seems to be an effective way to promote motivation and learning in education, which consists of the introduction of game elements in non-recreational contexts, in order to provide users with game-like experiences [16, 20]. Specifically, gameful systems are often employed in education to increase motivation and promote learning. Despite gamification is often effective when applied to education [6, 32], there is evidence of unsuccessful or negative outcomes [48] (see [41] for more details). The lack of effectiveness of gameful systems is often connected to flaws in the design [10, 29, 32, 43], such as the adoption of a *one size fits all* approach, and gamification designers are now focusing on the importance of personalizing the design based on the target's needs and characteristics [30, 32]. Given that one of the objectives of the SmartGame is to lead children to re-discover interpersonal relationships in person, we decided to focus on the cooperative modality.

1.1 Rationale behind the project

SMARTER [3] is a tangible IOT device consisting of a NodeMCU ESP8266 board connected to 5 RFID readers, a speaker, and an RGB LED used to provide children with audio-visual feedback (Figure 1). Each RFID reader represents a space in which children can position a tile (number, symbol, or operator). Through SMARTER, children can compute math operations and other simple exercises. Despite the potential of SMARTER, the device has some limitations in the possibility of visualizing the text of the exercise and creating a learning path with multiple activities, or increased difficulty. The idea behind the addition of a gamified web-app to SMARTER is threefold. 1) The application will allow children to have a better visualization of the exercises. Furthermore, with the aid of the web-app it will be possible to deliver children with more specific

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activities. 2) It will allow teachers to tailor the activities and the gamification elements based on students' needs. Gamification elements will support children's motivation and fun and encourage them to try and practice all the activities proposed by the teachers. 3) The application will support a cooperative modality in the use of SMARTER since there is clear evidence of the benefits of cooperative learning in traditional activities such as the promotion of motivation and well-being, as well as brighter performances and the willingness to spend more time on the task [2, 28].

1.2 Research questions

One of the aspects related to the personalization of gameful systems is the choice of the game modality [7], intended as the way in which goal structures in gameful systems can shape the interaction between users. As suggested by the *Social Interdependence Theory* [17, 27, 33], and later on in video games [35] and gamification [40], we can divide the game modality into i. individual, ii. cooperative, iii. competitive, and iv. cooperative-competitive. In the literature, there is evidence of the different effects that game modalities have based on the target users' interpersonal, demographic, and cultural differences [30, 31]. For example, Busch et al. [12] studied the continuum between masculinity and femininity, and reported that social status and competition were more effective in people close to the femininity end of the continuum, while Itoko et al. [24] suggested that competition may be more suited for the younger population, rather than older users. In fact, while it can be effective [21, 25], the competitive modality does not always represent the best solution for motivating and engaging users in gameful systems [13, 39]. In fact, cooperation, and a mixture of cooperation and competition seem to be more appreciated than the competition in the few existing studies (e.g. [13, 39]). In the definition of cooperation in the *Social Interdependence Theory*, Deutsch talks about positive interdependence to express the compatibility of goals between participants in a cooperative setting [17, 18]. In this sense, cooperation represents a broad pool of situations, from simply sharing the final goals, to actually working together on the same task. Therefore, our first research question is: RQ1 - Do different levels of interdependence in cooperative gamification impact the effectiveness of gamification? Specifically, are there any differences in the perceived fun and performance? Since we think that is important to give teachers the opportunity to create new activities and modify the gamification design in order to personalize the SmartGame and meet their students' needs, we aim at defining a simple and effective way to implement these two features: RQ2 - How can we support teachers in the personalization of the activities? RQ3 - How can we support teachers in the personalization of the gamification elements? And in particular, how can we guide them in the creation of new levels, missions, and badges? Finally, once all the features will be implemented, we want to verify that the SmartGame is actually meeting our objectives: RQ4 - Does the SmartGame reach sufficient levels of usability and user experience when teachers try to personalize the activities and the gamification rules? RQ5 - Is the SmartGame effective in increasing students' motivation and learning? RQ6 - Is the cooperative modality of the SmartGame effective in fostering interpersonal relationships in children?

Table 1: List of game elements included in the SmartGame according to Toda's et al. [47] taxonomy.

Category	Game elements
`Performance`	Points, levels, progression, acknowledgment
`Personal`	Objective
`Social`	Cooperation

Table 2: Set of actions that users can perform in the SmartGame and related consequences.

User's action	Consequence
`Insert tile`	Get feedback on SMARTER
`Complete exercise`	Continue to the next exercise in the level
`Complete level`	Gain experience points
`Complete level`	Unlock the next level of the game
`Complete level`	`If` enough experience points are collected, level up
`Complete level`	`If` the conditions are met, gain new badge
`Gain a badge`	`If` available, unlock new missions

In section 2 we present the SmartGame, along with its gamification design. In the same section, we present the results of a focus group carried out with teachers, with the aim of adjusting the SmartGame design based on teachers' and students' needs. In section 3 we define the ongoing experiment through which we aim at answering to RQ1, section 4 we define the future studies linked to the further development of the SmartGame (RQ2, RQ3, RQ4, RQ5, and RQ6). Finally, in section 5 we present the conclusions of our work.

2 SMARTGAME

In SmartGame (Figure 2) children are presented with a set of activities, which are called `games`: each game can be solved through the use of one or more SMARTER, it represents a different type of activity and is divided into levels based on their difficulty. Each level contains multiple exercises of the same type and difficulty. After completing the activity level, students can collect points, unlock new levels or new activities, level up, and earn badges by completing missions. The whole design is supported by a cooperative structure, for which the points and badges collected, as well as the missions and the progressions between levels, are shared by the whole class. As further described in section 3 also the structure of the activities fosters cooperation between students while using the SmartGame.

In the definition of the SmartGame, we decided to include a limited number of game elements to create simple game rules that children could easily understand. According to Toda's et al. [47] taxonomy, the game elements selected are *points, levels, progression, objectives, acknowledgment*, and *cooperation*. The full description of the game elements is presented in Table 1, while the actions that users can perform in the SmartGame and their consequences are listed in Table 2.

Figure 1: Pictures of SMARTER. On the right, example of an exercise supported by SMARTER.

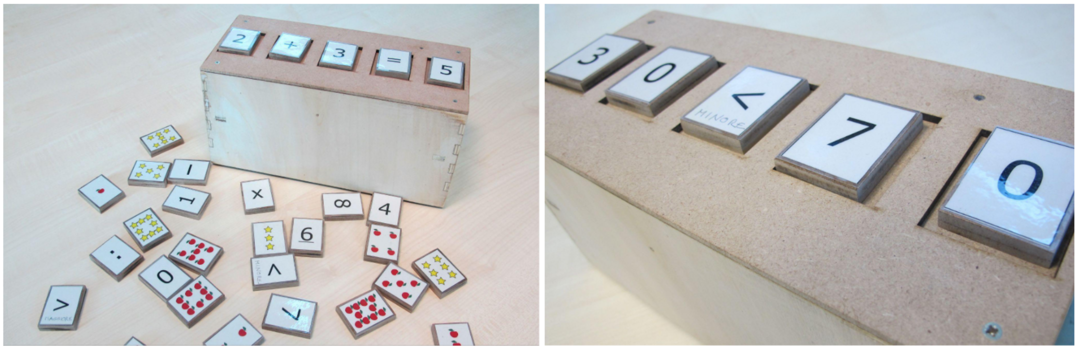

Figure 2: Screenshot of the SmartGame. From the left: example of a set of games, each one made of 3 levels; the conclusion of an exercise, in which children gained 2 experience points (acorns) and a badge; the class' profile page.

2.1 Focus group with the teachers

Before proceeding with the web-app development, we carried out a focus group with seven primary school teachers, most of whom teach math. The focus group was conducted online by two of the authors. The discussion was guided by the use of slides, each containing a brief description of the topic of the discussion, along with pictures of SMARTER and the SmartGame. In order to understand if SmartGame could be appreciated and actually helps teachers in class, we presented them SMARTER and our preliminary idea of the SmartGame, in which we focused mainly on the cooperative modality. After a brief explanation of the tools, we asked the teachers about the benefits that the SmartGame would add to the use of SMARTER, along with the problems that could possibly rise for them and for their students. When asked what they thought, teachers reported that combining SMARTER and the web-app could represent *"positive addition"* and that the SmartGame could represent "*new possibilities to learn*". In particular, Participant n°2 reported that despite liking the idea of the web-app – especially to introduce children to the digital world – implementing only the cooperative modality could be limiting ("*I would find useful to have many options, so the single child, cause I don't find it discriminating towards the rest of the class, especially when you use the game for a single child with difficulties and they need the feedback, and not that the results get mixed the whole class'. So I think that it could be useful to have the option for single players, teams, and classes and that the teacher can choose between the three*"). Furthermore, two teachers reported that adding the SmartGame could be a useful way to *"involve the whole class"* in the activity. Participant n°2 also noted that the SmartGame could facilitate teachers in correcting their learning paths and in particular *"to monitor because it's easier to visualize the results and see if everything is going in the right way, and to correct ourselves* – teachers – *immediately if we see that we are not taking the right path"*. When talking about their students, the participants reported that the SmartGame could help children in *"working with some objectives in mind"* and to *"have autonomy while working"*. When talking about the difficulties that children could have using the SmartGame, an interesting debate about feedback emerged. One teacher pointed out that showing the correctness of the exercise on the interactive whiteboard could embarrass some children. Given the importance that feedback has in learning [22, 34, 49] we discussed what could be the best solution in order to provide children with feedback without exposing them to uncomfortable situations. In particular, teachers liked the possibility to give feedback to the children through the led in SMARTER, without showing it in the SmartGame, so that students can be alerted when they make a mistake, without sharing it with the whole class. Finally, we asked the teachers what they thought about the theme of the SmartGame (the wood and the animals), and the game elements included in the design. Participants reported the theme to be appropriate and suggested other suitable themes, such as the seaside and the space.

As for the game elements, Participant n°1 appreciated the possibility to unlock new levels, since *"it is something that usually excites children"*. Also, Participant n°5 said that displaying the stacking of the levels vertically, instead that horizontally, could be effective to convey a sense of increasing difficulty and progress, since at that age *"children think in a concrete way, and seeing something elevated could motivate them more"*. Finally, Participant n°2 expressed the desire to have the possibility to personalize the activities and the objectives in the SmartGame, in order to have the possibility to work on specific topics and give the opportunity to children to create exercises for their classmates.

Considering the teachers' opinions, we decided to introduce an individual modality to the gameful system, eliminate the feedback about the correctness of the tiles inserted in the SmartGame – leaving it only in the SMARTER – and change the visualization of the levels for each activity, preferring a vertical display over a horizontal one. As for the personalization of the activities and the game elements included in the SmartGame, the focus group reinforced our belief about the importance of providing teachers with end-user programming tools.

3 CURRENT STUDIES

3.1 RQ1 Do different levels of interdependence in cooperative gamification impact the effectiveness of gamification?

With an ongoing experiment, we aim at understanding how different levels of cooperation can impact fun and learning in primary school children. We defined a condition, called *High Positive Interdependence (HPI)*, in which both the gamification structure and the activities included in the SmartGame will be cooperative; and a second condition called *Low Positive Interdependence (LPI)*, in which we will maintain the very same cooperative gamification design, while the activities included in the SmartGame will be carried out individually. In both conditions, two SMARTERs will be connected to the SmartGame.

3.1.1 Participants and procedure. A sample of 54 children between 6 to 7 years old (sample size calculated with G*power v 3.1.9.4) will participate in the study. Before using the SmartGame children will evaluate their level of fun through a 5-point Likert scale composed of smileys, which we will use as a baseline. After that, the couples of children will take part in both the HPI and the LPI conditions for 30 minutes each approximately. In order to control the boredom levels and the novelty effect [14]. After each condition, children will complete the Fun Toolkit [42], which contains the Smileometer (the same scale used as a baseline), the Fun Sorter (though which children will be asked to order the game elements based on their preferences), and the Again Again table (in which we will ask children if they would like to play again with SMARTER and the SmartGame). Also, the time spent on the activities and the number of mistakes will be used as indicators of children's performance.

3.1.2 Hypotheses. We expect Hp1 the level of interdependence to module the fun perceived by children in the two conditions, and the HPI to be considered more fun than the LPI condition. Furthermore, we expect Hp2 children in the HPI condition to make fewer mistakes since they have the possibility to discuss together the solution of the exercise. For the same reason Hp3 we expect children in the HPI condition to spend more time on tasks.

4 FUTURE DEVELOPMENTS

One of the advantages of SMARTER is the possibility to personalize and create new games through a dedicated interface called SENSATION [3, 15]. This end-user programming (EUP) web-app was designed and developed to guide non-programming experts – such as teachers – in composing trigger-action rules using language primitives. In order to answer to RQ2, and give teachers the possibility to personalize the games included in the SmartGame and tailor the activities to their students' needs, we aim at implementing in the SmartGame a EUP interface similar to SENSATION. In order to give a sense of continuity to users, we plan on integrating the interface directly into the SmartGame. The personalization of game elements is a crucial point in gamification since it requires programming expertise, and this is often limiting for designers, who have little to no experience in programming, let alone the end-users. Similar to RQ2 we aim at investigating how to support teachers in the personalization of the gamification elements in the SmartGame (RQ3). Also in this case, we plan to integrate the EUP interface directly into the SmartGame, to provide teachers with a continuous user experience. In order to understand if the SmartGame is actually meeting our objectives, we aim at carrying out a complete evaluation of the effects of the SmartGame both on teachers and students. In order to answer to RQ4 we will perform a usability and user experience evaluation for teachers, to be sure that our web-app is easy-to-use and intuitive, and that teachers are able to create activities and personalize the game rules in the EUP sections. After that, we intend to bring SMARTER into the classes, in order to evaluate its effectiveness in terms of increasing motivation, learning, and fostering positive interpersonal relationships (RQ5 & RQ6).

5 CONCLUSIONS

In the current manuscript, we presented the SmartGame, a gamified web-app connected to a tangible IOT tool, designed to support children in learning math and fostering social relationships. The project is still in its early stages and no quantitative data are available. Despite that, teachers participating in a focus group reported appreciating the SmartGame as a useful support in class.

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