Multiplayer Serious Games Supporting Programming Learning

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Abstract: Computational thinking (CT) is crucial in education for providing a multifaceted approach to problem-solving. However, challenges exist such as supporting teachers' knowledge of CT and students' desire to learn it, particularly for non-technical students. To combat these challenges, Computer Supported Collaborative Learning (CSCL) has been introduced in classrooms and implemented using a variety of technologies, including serious games, which have been adopted across several domains aiming to appeal to various demographics and skill levels. This research focuses on a Collaborative Multiplayer Serious Game (MSG) for CT skill training. The architecture is aimed at young students and is designed to aid in the learning of programming and the development of CT skills. The purpose of this research is to conduct an empirical study to assess the multiplayer game gameplay mechanics for collaborative CT learning. The proposed game leverages a card game structure and contains complex multi-team multi-player processes, allowing students to communicate and absorb sequential and conditional logics as well as graph routing in a 2D environment. A preliminary experiment was conducted with four fourth-graders and eight sixth-graders from a French school in Morocco who have varying levels of understanding of CT. Participants were split into three groups each with two teams and were required to complete a 16-question multiple-choice quiz before and after playing the same game to assess their initial structural programming logics and the effectiveness of the MSG. Questionnaires were collected along with an interview to gather feedback on their gaming experiences and the game's role in teaching and learning. The results demonstrate that the proposed MSG had a favourable effect on the participants' test scores as the scores of 4 of the teams increased and 1 remained the same. All students performed well on the sequential and conditional logics, which was significantly better than the achievement of the Bebras test of the graph routing. Furthermore, according to the participants, the game provides an appealing environment that allows players to immerse themselves in the game and the competitive aspect of the game adds to its appeal and helps develop teamwork, coordination, and communication skills.

Keywords: Collaborative learning, Multiplayer Serious Games, Game design, Computational Thinking, Introductory programming

1. Introduction

Collaborative learning is an approach to teaching and learning where students work together in groups to complete tasks and promotes a positive learning atmosphere where interaction and negotiation trigger learning (Chowdhury et al, 2018). The use of computers to promote collaborative learning has been extensively researched, with a recent focus on using game environments as a learning framework. Moreover, game-based learning has evolved due to the introduction of advanced technologies, resulting in the deployment of Serious Games (SGs) in various fields and for a wide range of audiences. By managing interactive variables inside game environments, learners can build an intuitive grasp of the desired knowledge.

Multiplayer Serious Games (MSGs) combine the potential of serious games with collaborative learning processes, helping to develop teamwork and collaboration skills. However, the use of SGs in education raises questions regarding how to align desired learning outcomes with game objectives and features, and whether they can promote education. There is a risk of overemphasizing motivational factors, which could undermine intrinsic motivation. If the entertainment aspect of the game dominates all aspects of the game, students may lose focus and disengaged from the learning process, but if the game isn't appealing or amusing, students will lose interest and thus won't understand the full game. The creation of effective SGs requires the application of advanced technologies and thorough research into game design that can effectively combine educational and entertainment goals.

In this paper, a collaborative multiplayer Serious Game which is adapted from the unplugged game Robot City (Kuo & Hsu, 2019; Hsu & Liang, 2021) and enables game-based collaborative learning for programming is proposed. The targeted audience is students at an elementary school. The approach aims to study the impact of collaborative learning on computational thinking (CT) knowledge and skill sets by implementing a multi-team, multi-player system in a card game-structured MSG. The purpose of this research is to provide a practical framework for integrating programming content into multiplayer game gameplay dynamics and aims to answer the following research question: 1) How can Computer Supported Collaborative Learning (CSCL) and Serious Games be used to support the teaching of Computational Thinking?; 2) How effective is the Collaborative Multiplayer Serious Game (MSG) in improving the programming skills and CT understanding of young students?; 3) How do the gameplay mechanics of the digital version of the card game impact the engagement and motivation of learners in improving their computational thinking skills?

2. Related Work

SGs are classified into different taxonomies based on multiple variables, including the application domain, target audience, skillsets, and intended learning outcomes. Squire et al (2004) presented 'Supercharged!', an SG with the primary goal of teaching physics, notably electromagnetism, to both higher education and high school students. To achieve the objective, players employ electromagnetism physics laws to propel their spacecraft and navigate inside a 3D dimensional world by inserting charging particles. Rooney (2012) used a serious game to promote in-house cleanliness to students aged 6 to 12. The proposed SG employs a similar atmosphere and characters to Half Life 3, a popular game at the time, with the user navigating through the 3D environment and completing in-house chores. This research emphasizes the importance of fidelity in SG.

Considering the context of collaborative learning, the integration of a multiplayer system component within an SG is an important addition and provides means for learners to interact with each other during the game. Interaction can be either cooperative where players cooperate in terms of resource sharing to complete tasks, or competitive where the players compete against each other to achieve the best results with specified performance evaluation metrics such as score and time (Wendel et al, 2012). There are many parameters to be taken into consideration when choosing between the types of interactions at the initial stages of the game conception including the game environment, the number of players targeted, player communication and social issues (Wendel et al, 2016). The major parts of design guidelines are discussed by Zea et al., (2009). Five essential aspects for effective collaborative work have been identified, which include: collaborative learning through group processing (enabling groups to exchange ideas and share progress), social skills development, positive interdependence (using a well-designed matchmaking system to create mutually beneficial groups), promotive interaction (encouraging and acknowledging each player's achievements), and individual accountability (providing sufficient individual feedback and monitoring for each student).

Recently, several MSGs have been developed for education. Garzotto (2007) proposed a cooperative MSG called Pirates Treasure Hunt to introduce European elementary school students aged 7-10 years to different cultures, Seah et al. (2018) developed a nutrition and health education game using Bingo and Lo et al (2013) proposed VocaMomo, an MSG to teach English vocabulary using a combination of Monopoly and Scrabble. The usage of existing popular games as a base for the serious game is a common pattern. Several studies have recorded the usage of the online platform Second Life to assist seminar activities, lectures, and other educational activities. Through the provision of unique support for distributed groups, online virtual worlds have outstanding capabilities for promoting effective distance learning using online chat systems and document sharing (Anderson et al. 2010).

The teaching of programming topics to young children raises debates about the most efficient ways to teach this content. Chang et al (2010) implemented a multiplayer serious game for assessing student's Java programming skills where players complete in-game tasks to receive gold/experience and reveal parts of the village map. The tasks range from multiple-choice questions to writing Java code. Moreover, Shabalina et al (2017) proposed a serious game for teaching programming skills to university students. The gameplay consists of finding and executing code to move a snake across the map to fulfil tasks to get rewards. Players can use a team chat to discuss strategies. This type of game is changeable or customizable as the snake game could be substituted with a car racing game or any other type of game. Malliarakis et al (2013) implemented a serious game to introduce programming to young pupils. The gameplay takes place in an action-adventure environment where a team tries to defend a castle whilst another team attacks it. To move across the map, the teams must succeed at finding the right pseudocodes related to the in-game environmental situations using the drag-and-drop tools provided. This provides the learners with a deeper understanding of the mechanisms involved in the pseudocode.

3. Methodology

To support computational thinking, the game Robot City (Kuo & Hsu, 2019; Hsu & Liang, 2021) was adapted into a digital game using Java. The board game taught structural programming concepts, such as sequential, conditional, and repetitive structures to help seventh-grade students learn computational thinking. The digital version, which is called Online Robot City, retains the same gameplay mechanics but also features a manual grouping procedure, a 2D gaming world, and in-game features including a chat system to enhance communication between the game's various stakeholders. Players can learn programming concepts while engaging in immersive gameplay, allowing them to apply their computational thinking skills in a fun and interactive way.

To successfully integrate programming content into multiplayer game gameplay dynamics, a practical framework must be provided to make decisions about the necessary components of the design of MSGs. To begin, mechanics must be developed to specify what players can and cannot do in the virtual world and it is important to strike the correct balance between learning outcomes and entertainment. The proposed multiplayer serious game was created using an MSG design framework proposed by Yusof et al. (2010). This is a conceptual model framework for game designers and educational practitioners to employ when creating serious games for academic learning. The framework combines learning and educational theory with gaming requirements. The overall structure of the framework is comprised of 2 major sections: (1) the matchmaking system and (2) the game environment. The matchmaking process takes place in the lobby, which is illustrated in Figure 1. Players select tables that correspond to the games they want to play. A minimum of four players (2 per team) are required to begin a game, and sockets are opened for each user at this stage to signal the start of each session. Users are instructed to wait until there are four players before the game begins.

Figure 1: Robot City lobby

Following the matchmaking, the players join the game environment shown in Figure 2. The game's core concept is for players to work together in teams to collect resources on the grid and complete tasks. An intra-team chat system is shown at the bottom right of the screen. At the beginning of the game, each player is dealt eight cards as a starting hand. These cards will be used to navigate around the board's grid and collect resources and materials to fulfil tasks. At the end of each round, a new set of cards is selected. For the development phase, as shown in Figure 3, there are two degrees of card complexity: level 1 sequential cards and level 2 conditional cards. The sequential cards include basic operations such as move forward, backward, left, right, and U-turn and the conditional cards involve more intricate programming tasks, such as turning left if a barrier is in front.

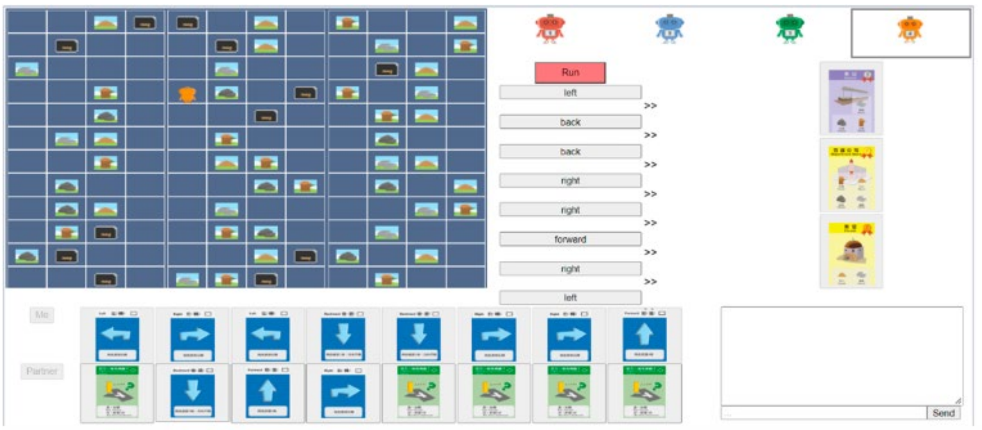

Figure 2: Robot City game environment

(a) (b)

Figure 3: (a) Level 1 Sequential cards and (b) Level 2 conditional cards

Each player can exchange cards with their teammates and select up to 8 cards per turn to traverse around the board. The commands associated with each card are executed in the order specified by a computation complexity system. As a result, the robot walks in an appropriate direction collecting resources (sand, wood, stone and steel) which are arranged on a grid. Furthermore, construction cards are used to depict the mission that is allocated to players at random. Each card depicts a structure as well as the materials required for its construction. As shown in figure 4, each card has one of three levels of difficulty. The higher the difficulty of the mission, the more material is required to make it but the higher the reward associated with it. The grid contains different components including the GPU which is the player's robot's starting place, a sim card which serves as a doorway for players to teleport from one sim card to another, and a barrier which represents an obstacle.

Figure 4: Construction cards (3 levels of complexity: Level 1 – 3 points, Level 2- 5 points, Level 3 – 7 points)

4. Preliminary Experiment

4.1 Participants and Experiment Procedure

A preliminary experiment was conducted to evaluate the effectiveness of Online Robot City. This study involved 12 participants (4 in 4th grade and 8 in 6th grade) from a French school in Morocco. The participants (5 Male, 7 Female, aged 9-12) were divided into three groups based on age, with each group consisting of four students. Within each group, two teams were formed, with two students in each team. Groups 1 and 2 consist of 6th grade students and Group 3 consist of 4th grade students.

The study consisted of three phases: a pre-test quiz, gameplay, and a post-test quiz. Participants were asked to complete a 16-question pre-test quiz (Kuo & Hsu, 2019; Hsu & Liang, 2021) comprising multiple-choice questions before starting the game to assess their initial programming skills. The test items included three dimensions which are sequential logics, conditional logics and the Bebras test of graph routing. After playing the game, participants completed a post-game quiz containing the same questions in different sequence, and the results of both quizzes were compared to determine any differences in grades. In addition to playing the game, participants also provided feedback on its use by completing a 33-question questionnaire. The questionnaire collected CT scales for computer literacy education using a 5-point agreement scale (1 = completely disagree, 2 = slightly disagree, 3 = neutral, 4 = slightly agree, 5 = completely agree) with 18 items in total. There were 6 items for collecting cognitive loads with 7 point Likert scale; in the meanwhile, there were 9 items for collecting the perceptions of users. Furthermore, the participants were interviewed to also obtain their feedback on their gaming experiences, preferences for game elements, and the game's role in teaching and learning.

4.2 Results and Data Analysis

Pre-test scores for each group in Figure 5 reveal that students have varying levels of understanding of algorithmic thinking and problem-solving. Furthermore, compared to the 4th grade students (Mean = 7.5, S.D = 0.5), the 6th grade students had a deeper understanding of computational thinking and problem-solving (Mean = 11.5, S.D = 1.12) because IT and numerical sciences was introduced in 6th grade.

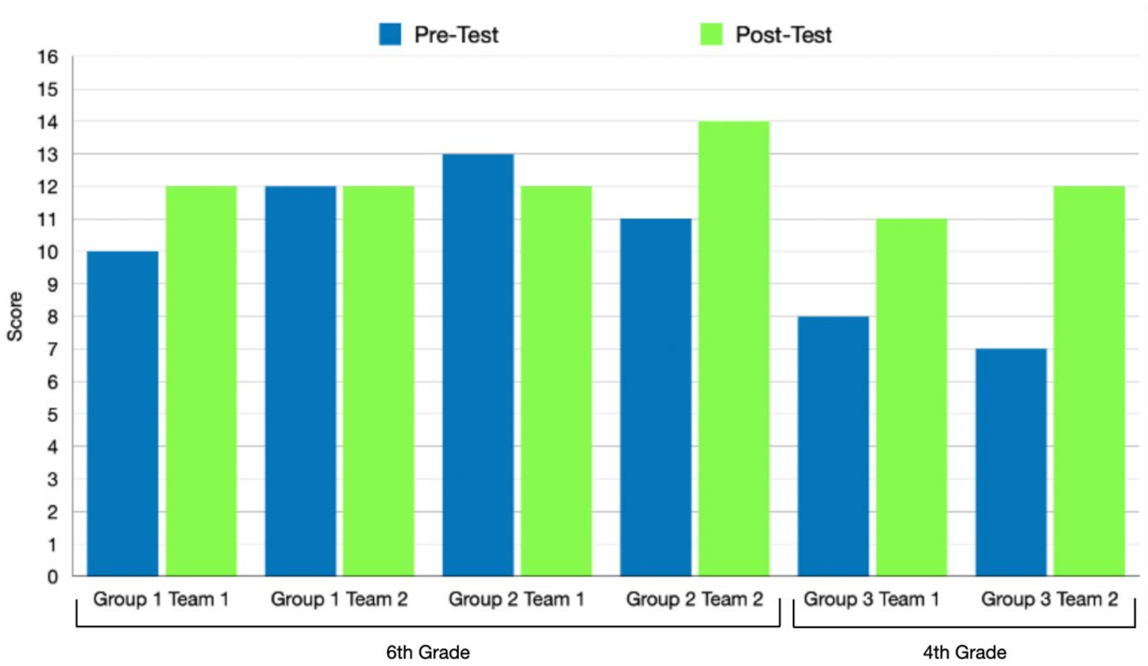

Figure 5: Number of correct answers for each time in the pre-test and post-test quizzes

After taking the pre-test quiz, participants were introduced to the game mechanics and rules before engaging in the gameplay phase, which lasted around 1 hour and 30 minutes. During the trial phase, participants were only issued with level 1 sequential cards, which include forward, backward, left, right, and U-turn. Players were able to immediately immerse themselves in the gaming experience because the operations were simple to understand and did not face any technical issues in joining the tables assigned to them. Each team was given only one easy task (a construction card composed of 2 materials). Some players began to communicate with each other, trade cards, and travel around the map, however in general there was still little communication between stakeholders. Only the two teams in Group 2 were able to collect enough resources to complete the missions. Despite the players being acquainted with the game rules and cards during the pre-test quiz, some struggled during the game suggesting the game environment interface was a bit confusing.

After the trial game was completed, the players were given a more detailed explanation of how the scoring system works. The gamers were then placed in real scenarios. Each squad was given three missions at random. For 6th graders, the game lasted around 60 minutes, while for 4th graders, it lasted about 40 minutes. Figure 6 presents the score achieved by each team. It is worth noting that team 2 of group 2 achieved the highest score but team 1 could not solve any missions and received 0 points potentially due to team 2's strong performance. In group 3, team 1 completed only 1 mission with a total score of 3 and team 2 could not solve any. When placed in the real scenario game, the participants more often used the chat system and were conversing with one another about gaming problems, discussing their working relationships, and assisting and boosting each other's success. Some groups implicitly had a team leader and seemed to do better than those that did not. For the teams with leaders, instead of focusing on their individual tasks, they were discussing strategies and collecting resources for each other. Players had to coordinate their actions because of the diverse resources, and they had to help each other because of the card swap option.

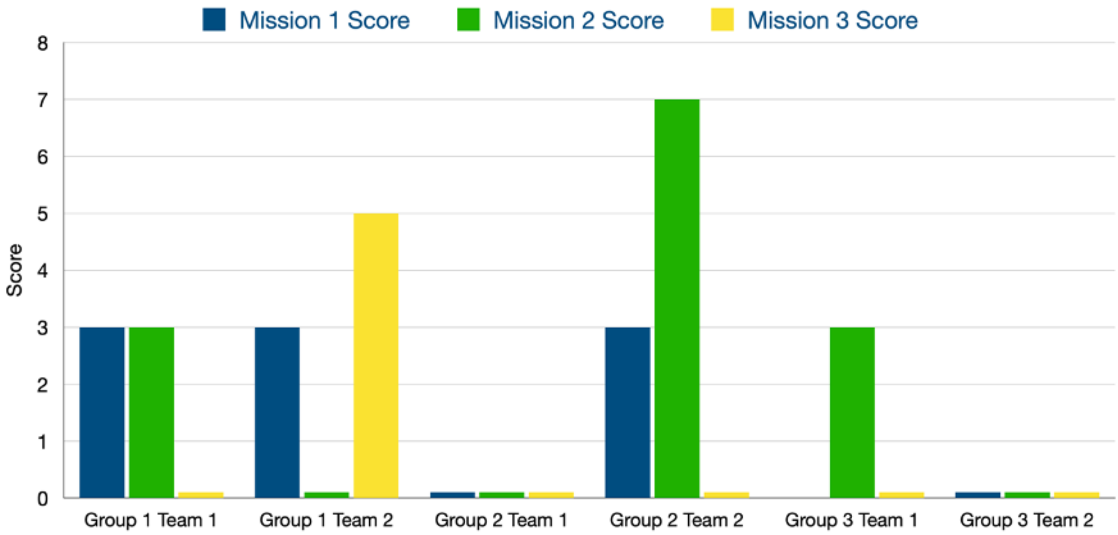

Figure 6: Scores for each team for each mission

Following the gameplay, each team took a post-test to assess their performance concerning computational thinking after playing the game. As shown in Figure 5, apart from Team 2 of Group 1 who achieved the same score, and Team 1 of Group 2 whose score dropped by one, the rest of the teams had different levels of score improvements. According to figure 6, although team 1 of group 2 and team 2 of group 3 both got zero points in all of the missions, the different performances of their opposing teams effected their learning performance differently in the post-tests. In other words, team 2 of group 2 got the highest scores in missions 1 and 2 because of their good game performance which brought them to the highest post-test score. However, this might have caused team 1 in the same group to feel frustrated and confused during the gameplay causing their post-test score to fall slightly.

After comparing different topics in their post-test, it was found that the correct rate of sequential logics was significantly higher than the correct rate of Bebras test of graph routing ($Z=-2.214^*$, $p=.027<.05$). In the meanwhile, the correct rate of conditional logics was also significantly higher than the correct rate of graph routing ($Z=-2.226^*$; $p=.026<0.5$) based on the results of Wilcoxon signed-rank test which is a non-parametric statistical hypothesis test.

For collecting feedback on the game and its role in teaching and learning, the participants were also required to respond to a questionnaire. Participants were first asked about their learning background and how they approach solving complex problems. When asked if when solving problems, they usually try to find the key points of a problem to understand it better, 7 (58.3%) of the participants strongly agree and 5 (41.7%) agree, and when asked if trying to apply familiar solutions helps to solve complex problems 7 (58.3%) of the participants strongly agree, 3 (25%) agree and 2 (16.7%) strongly disagree. Furthermore, when asked if they usually split large problems into several smaller ones, 7 (58.3%) of learners strongly agree, 2 (16.7%) agree and 3 (25%) are neutral.

The average effects of CT literacy are shown in Table 1 by employing the questionnaire developed by Tsai (2021). The five dimensions are evaluation (Cronbach alpha = 0.83), Abstraction (Cronbach alpha = 0.81), Decomposition (Cronbach's alpha = 0.74), Generalization (Cronbach's alpha = 0.75) and Algorithmic Thinking (Cronbach's alpha = 0.77). The overall reliability of the CT scale for computer literacy education (the value of Cronbach's alpha) is 0.91. The students performed well significantly on the generalization scale which is also normal distribution (K-S = 0.224; $p = 0.099$, $p > 0.05$) in the results of this study. Due to the small sample size, some scales like abstraction, decomposition and algorithmic thinking are non-normal distribution while the means of the abstraction and decomposition dimensions are both higher than 4 in the 5-point Likert Scale. The means of algorithmic thinking ($M=3.85$) and evaluation ($M=3.97$) are relatively low although both are higher than 3.5 on average. Overall, the results of the computational thinking literacy are good while the overall mean for CT literacy is 4.11 ($SD=0.35$).

Table 1: The descriptive statistics for computational thinking literacy scales employed from Tsai et al. (2021).

Scales	N	Mean	SD
Abstraction	12	4.29	0.37
Decomposition	12	4.03	0.59
Algorithmic Thinking	12	3.85	1.07
Evaluation	12	3.97	0.81
Generalization	12	4.33	0.48

Participants were asked about Cognitive Load based on the questions used by Wang et al (2014, 2020) and answered on a scale from 1-7 where 1 is ”very little” and 7 is ”a lot”. As shown in table 2, the effects of understanding the activity purpose and learning CT were both less than 4 (neutral). This suggests that the learning activities in the experiment were moderate. Also, distraction, stress and frustration were all less than 3 suggesting that the game didn’t cause mental overload to learners. The overall cognitive load is 2.67 on average (SD=1.42) with its overall Cronbach's alpha value of 0.836. The dimension of mental effort which is external cognition includes item 1 and item 2. The mean of mental effort is 3.25 (SD=1.67), referring to the fact that the instructional material is well designed. The dimension of mental load which is internal cognition includes items 3 to 6. The mean of mental load is 2.39 (SD=1.64), implying that the difficulty degree of the content is proper for the students.

Table 2: Responses to questions about cognitive load (N=12)

Item	Response (1: ”very little” - 7: ”a lot”)	Mean	S.D.	Median
1	How much effort was required to understand the purpose of the learning activity using this game?	3.42	2.07	3.5
2	How much effort was required to understand CT content in this game?	3.08	1.78	3
3	How much did this game distract you from learning CT?	2.08	1.08	2
4	How discouraged, stressed or irritated did you feel while using the game?	2.27	1.56	2
5	Were you frustrated whilst playing the game?	2.50	1.93	2
6	Were you frustrated at the end of the game?	2.42	2.27	1

An interview was conducted with team 2 of group 2, who were the group with the highest score, to collect more feedback on the game's functionalities and areas of improvement covering the topics of Computational Thinking and User Experience. Regarding computational thinking, according to these participants, the game provides an appealing environment that allows players to immerse themselves in the game and boost their focus. The competitive aspect of the game, which allows different teams and groups to participate, adds to its appeal. The chat service is a valuable feature that allows teams to communicate easily. More popup messages and hints would make the MSG gameplay more accessible. Other possibilities include modifying the grid background, for example, to vary the user interface.

5. Conclusion

Our design of a theoretically based collaborative serious game combines the theoretical knowledge of collaborative learning and game design into a practical application that takes advantage of game mechanics. The main aim was to create favourable conditions for collaborative learning and to structure players’ actions to maintain social interaction and collaborative activities. The multi-team multi-player board game utilizes game mechanics and rules to help players progress and achieve missions while implicitly injecting programming material into these rules, thereby enhancing their programming skills. The game also offers chat and card swap tools to encourage cooperation. The proposed MSG attempts to improve the learning processes by providing appealing, motivating, and effective tools that can also help students and teachers form meaningful relationships. The results demonstrate that the MSG had a favourable effect on the participants, as they were able to increase their test scores and reported high levels of satisfaction with its entertainment value.

This study has demonstrated the effectiveness of SGs thus far, but the potential of SGs for instruction providing compelling plots and contexts in which players can effectively and efficiently acquire new knowledge where progress can be accurately verified is still unrealized. However, this study is a first step towards creating a common language and understanding among instructional and game designers and the MSG designed to teach programming has yielded positive results and has proven to be both efficient and engaging. Recognizing educational game design trends is necessary to align educational and game design viewpoints. As a result, our goal will be to better recognize and define collaborative game design patterns so that they can be used more widely. The implications of different game design patterns on the establishment of collaboration and social interaction will be the subject of our future research.

In the future, a variety of strategies for improving the user experience can be examined and applied. For example, the game may benefit from more storytelling to boost user participation and comprehension and other services, such as audio queues can also be introduced to help teammates communicate more effectively. In addition to the conceptual improvements, the programming material could also be enhanced. The introduction of more complex card operations (levels 3, 4 and 5) will make the gameplay more interesting. The board game version is currently printed in Chinese only so that the conventional material could not be put into experiment in the French school. In the future, when the board game made of paper is also printed in different languages, it is encouraged the schools in Europe to do further empirical studies and to compare the different effects between the board game version and the digital game version. This will allow the students to hone their critical thinking skills whilst playing the game. Another goal of a follow-up study would be to evaluate the influence of such games on each student's knowledge acquisition process to regular in-class activities. To ensure adequate evaluation, the proposed game should be performed on a bigger sample. We did not assess any progress in social skills like teamwork, coordination, or communication, but we did see that the participants employed all of them during the game. This suggests that with the right game design, such talents can be explicitly improved.

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