Asteroid Escape: A Serious Game to Foster Teamwork Abilities

F.G. Pratticó, F. Strada, F. Lamberti, and A. Bottino

Politecnico di Torino, Department of Control and Computer Engineering, Italy

Abstract

Teamwork skills have become a fundamental asset in the labor market. Modern organizations are increasingly implementing team building activities, aimed to improve or assess their employees' skills. Research suggests that serious games could be promising tools capable to support the creation of engaging and effective team building experiences. However, the design and development of serious games targeting these activities is still sparse and requires further investigation. This work introduces Asteroid Escape*, an immersive serious game for team building, whose design was based on theoretical models on teamwork effectiveness. Although conducted on a restricted user sample, preliminary experiments suggest that tools like the devised one could positively contribute to ongoing research and implementation efforts targeting the exploitation of technology-enhanced learning methods for the development of teamwork skills and, more in general, of so-called soft skills.*

CCS Concepts

• ***Human-centered computing*** → *HCI design and evaluation methods; Mixed / augmented reality; Collaborative interaction;*

1. Introduction

Over the past decades, organizations have increasingly adopted team-based approaches in solving complex problems, since they enable the gathering of heterogeneous feedback from stakeholders with different perspectives, promote workplace synergy, motivate cohesion and can improve overall efficiency and productivity [SHB*15]. In order to effectively work and perform well in a team, an individual needs to possess a series of *soft skills* [HK12], whereas traditional learning curricula tend to overlook their relevance, promoting predominantly the development of *hard skills* [dFR13]. To fill this gap and improve collaboration among individuals, organizations have progressively found as beneficial the introduction of team building activities, aimed to enhance social relations and to define roles within workgroups.

Technology-enhanced learning (TEL) environments have proven to be valuable tools for developing and refining soft skills [MA09]. In particular, researchers underlined the potential of serious games (SGs) in this perspective [RUO15]. SGs represent a valuable alternative to traditional approaches, since they are able to (i) improve engagement and motivation, (ii) provide immediate feedback to user's actions and (iii) simulate a broad variety of scenarios that can be experienced with no risk. Despite all of the above, the research in the field of TEL for soft skills development is still sparse [CBM*12], and a few results have been reported in the literature. In particular, there are SGs focused on fostering specific teamwork-related skills without explicitly framing them in a team building context. Examples are ENACT [DMP*17], aimed to train and assess individuals' negotiation and communication abilities, and the SG described in [LLDK09], focused on teaching group decision making to emergency managers. Other works experimented with the use of commercial games (like World of Warcraft and Call of Duty) obtaining positive outcomes [MS11]. Finally, there are several works that developed new SGs specifically tailored to the considered goal. For instance, in Let's Team! [GER*14], players have to build collaboratively a small evolving civilization; the focus here is on how decision making can improve communication among peers. A similar example is NoviCraft [HBJL12], where players have to collaboratively solve puzzles to escape from a prison.

With the work reported in this paper, our aim was to provide a further contribution to the state of the art through the development of a new SG named *Asteroid Escape* (AE). The storyline of the game portrays a spaceship crew that has to find a way out of an imploding asteroid with the help of a remote operator. Different roles are associated with different tasks, which request players to deal with scattered (and limited) pieces of information.

The design of AE largely relied on the *input-process-output* (IPO) framework [McG64], a sound theoretical frameworks concerning teamwork and its effectiveness. *Inputs* include individual's, team's and task's characteristics and work structure, whereas a *process* is the set of activities through which a team interacts in order to achieve a final *output* (quantitatively and qualitatively measurable). According to IPO, the following crucial *processes* are involved in an effective team activity: (i) communication, (ii) coordination, (iii) problem solving and (iv) decision making. Improving these *processes* by organizing *process interventions* (i.e., implementing team building activities) can lead to better team performance. The main contribution of our work is that, differently than in SGs recalled above, it addresses directly or indirectly all these processes.

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We assessed the effectiveness of the designed approach through both qualitative and quantitative observations. Although results collected so far are based on a limited number of trials, they underline the potential of SGs as tools for strengthening team building skills.

2. The Game: Asteroid Escape

The game virtually takes place on a mining asteroid on the verge of collapse. The only spaceship left is stuck in the intricate set of mining tunnels and needs to be saved before the asteroid implodes. AE is a three-player game, in which players can take over two roles: ship *Crew* member (up to two) and *Navigator*. Each role has its own specific tasks and can access limited information. The *Crew* members are in charge of piloting the ship and have a direct view of the asteroid's tunnels and the obstacles they contain (Figure 1, left), but they cannot benefit of a tunnel map during navigation. The *Navigator*, who is virtually located in a remote space control station, must provide the *Crew* with navigation information and early warnings about forthcoming obstacles. To do so, he/she can exploit a 3D tactical map showing (i) the complete tunnel network, (ii) the current position and orientation of the ship and (iii) a color-coded abstract representation of various types of obstacles that the ship can face during navigation (Figure 1, center). A limited time interval to exit the asteroid (13 minutes) was set to solicit fast thinking abilities while preserving control effectiveness and accuracy.

Game design was aimed to foster three out the four critical teamwork abilities in the IPO framework, since a successful in-game outcome requires the players to (i) share partial information in a clear way (*communication*), (ii) make common decisions based on this partial information (*decision making*), and (iii) coordinate their activities in overcoming certain challenges (*coordination*).

Concerning the establishment of an effective communication, *Crew* and *Navigator* are required to find a shared vocabulary for two main reasons. First, in order to warn the *Crew* about possible issues during navigation, the *Navigator* must associate the abstract representation of each obstacle to its actual meaning (e.g., gates, tunnel collapses, out-of-control androids wandering in the tunnels, etc.). This meaning can be provided only by the *Crew* when the obstacle is reached. Second, the *Navigator* derives driving directions from the observation of a 3D map (thus, in a global way) and should be able to translate them for the *Crew* in terms of their local information (i.e., "turn left/right", where left and right are relative to both the forward motion direction of the ship and its orientation along this axis). Since communication is critical for the positive outcome of the game, we included an initial tutorial session where the *Navigator* is instructed to illustrate the *Crew* the mission's objectives and the ship's controls.

Coordination is enforced throughout the game experience in two ways. First, each *Crew* member is provided only with partial and complementary controls (Figure1, right); in this way, pilots are challenged to coordinate their inputs in order to effectively control the spaceship. The coordination between pilots is vital since they must avoid collisions (which may damage the ship and, eventually, destroy it), manage a limited amount of fuel, and promptly react to active dangers (e.g., enemy androids) by shooting at them. Additionally, coordination between *Crew* and *Navigator* is solicited by including tunnel portions where the ship's headlights do not work, thus requiring pilots to rely only on the *Navigator*'s indications.

Finally, in order to encourage *decision making*, all the players are required, during navigation, to discuss and reach a common decision on which is the best route based on (i) their current position and available information, (ii) the ship's status (fuel and damage) and (iii) the presence of obstacles (enemies or collapsed tunnels). We underline that, with this design, collaborative problem solving (the fourth relevant teamwork process defined in the IPO framework) is implicitly addressed throughout the game, whose goal is ultimately to solve an escape problem.

In a complete game session, all the players are supposed to take over the role of each *Crew* member and of the *Navigator*. By experiencing the gameplay three times, they are expected to reach an understanding of the difficulties faced by their teammates in previous turns, which should improve team cooperation, cohesiveness and, overall, remove disagreements by favouring critical thoughts on other players' behaviour.

For each game role we exploited a specific input-output technique, with the aim to maximize the sense of immersion while providing an interface as natural and user-friendly as possible. The *Crew* members are physically located in front of a large touch-sensitive interactive wall, which displays an immersive view from the spaceship's cabin and includes 3D interactive buttons that players can use to pilot the spaceship (Figure 1, right). Pilots are provided with a smartphone to operate the main ship's controls (i.e., directions and throttle), whereas the least frequently used commands (i.e., ship ignition and missiles launch) could be accessed on the touch wall. This choice allowed us to minimize the complexity of the hand-held interface, while providing a "direct" form of interaction (through the large touch display) with the digital contents.

The *Navigator* is located in a different room than the *Crew*, and relies on an Augmented Reality (AR) device (namely, a Microsoft's Hololens) to visualize a holographic representation of the tunnel map. Although, indeed, a desktop interface could be sufficient for this task, the AR-based display allowed us to "register" 3D information to the physical space surrounding the player. Thus, he/she can physically move in the environment to inspect the map from different perspectives and distances. This choice enables a natural interaction and fosters spatial presence, which are both key elements for improving immersion [SVDSKVDM01].

Overall, the system consists of three distinct applications connected by a client-server architecture. The server application is hosted on a workstation and is in charge of managing the current simulation state, controlling the projected interactive wall and collecting in-game analytics. The two remote spaceship's controllers and the AR viewer are connected as clients. *Crew* and *Navigator* communicate using a VoIP chat.

3. Experimental Evaluation

The effectiveness of the developed tool was investigated through a user study that involved 12 volunteers selected among Computer Engineering students at Politecnico di Torino. Volunteers were split in four teams of three people (with each team member not knowing

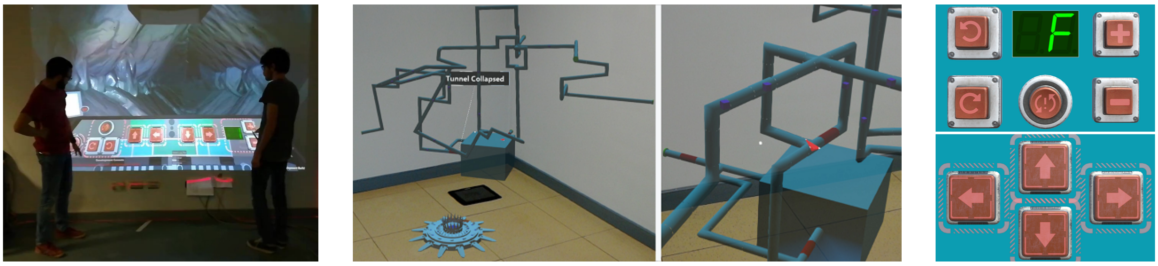

Figure 1: *Gameplay of Asteroid Escape: Crew's view (left), Navigator's view (center), and pilots' controllers (right).*

the others). Each team was requested to go through the tutorial and then play a complete game session by rotating roles three times.

Qualitative data were collected by means of three separate questionnaires. A pre-experience questionnaire (10 custom questions) aimed to collect information on personality traits [BKNS16] and to investigate the degree of relationship relative to other teammates (if any). A second intra-questionnaire (14 questions extracted and adapted from [BKNS16, SGL95]) was delivered after each game run to record personal subjective observations about team's performance and cohesion. Finally, after the last run, volunteers were asked to answer a post-questionnaire (105 statements) made up of four sections. The first investigated tool's usability from different perspectives, by combining the System Usability Scale (SUS) [B*96], the five attributes defined by Nielsen [NM90] and questions aimed to assess the perceived sense of immersion/presence and the appropriateness, for the tasks at hand, of the given display system [Kal99]. The second section aimed to assess game's likeability and effectiveness as a tool for developing communication abilities. The third section analyzed the impact of learning effects of the three game runs on the various game elements. The last section evaluated again team skills and performance by means of questions complementary to those asked in the intra-questionnaire.

Quantitative data were gathered by visually inspecting video footage recorded during gameplay and by logging game statistics such as ship collisions, average speed, decision time, tunnels navigated more than once, androids destroyed and so forth. A game performance score was also computed based on these variables, by combining them with positive and negative weights. Visual analysis was performed by an external observer, who labeled players' actions (i.e., events) according to a methodology inspired by [RdAR14]. The set of labels considered all possible communication channels between *Navigator* and *Crew* (N2C, C2N and C2C) and different events: information sharing (IS) (provide or ask), request action (RA) and complaint (C).

Regarding qualitative data, statements were rated on a Likert scale from 1 (strong disagreement) to 5 (strong agreement). Reverted statements were flipped to normalize scores. Overall, an acceptable to good internal consistency of the results for inter- and post- questionnaires was found (standardized Cronbach's Alpha equal to 0.85 and 0.75, respectively).

As for the usability (first section), head-mounted display (HMD) and wall projection (WP) were analyzed separately. Normalized SUS scores of 76.67 (HMD) and 74.37 (WP) in the 0–100 range

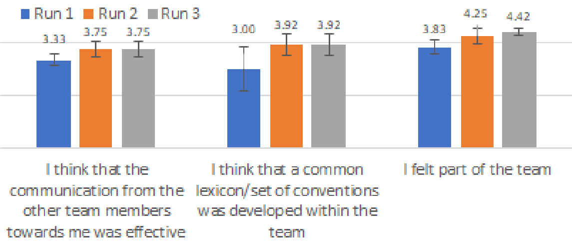

Figure 2: *Intra-questionnaire, most relevant results (three runs) show the positive progression of the considered dimensions.*

suggest a good to excellent usability of the designed tool. Similar conclusions can be drawn by considering Nielsen's attributes of usability. HMD mean scores (and standard deviations) were as follow: learnability 3.33 (SD = 1.10), efficiency 4.25 (0.72), memorability 4.33 (0.74), possibility to recover from errors 3.16 (0.69), and satisfaction 4.21 (1.01). For WP: learnability 3.80 (0.90), efficiency 4.17 (0.69), memorability 4.33 (0.85), possibility to recover from errors 3.08 (0.86) and satisfaction 4.08 (1.32). Finally, sense of immersion/presence was rated 3.75 (0.82) for HMD and 3.83 (0.90) for WP, whereas appropriateness scored 3.92 (0.64) and 4.08 (0.65) respectively for the two systems. In both cases, scores were quite high, confirming the level of usability reached by the devised tool.

Results of the second section (Table 1) shows that the experience was rated as largely capable to foster communication among team members. The third section of the post-questionnaire allowed us to confirm that replaying the game by taking over different roles did not introduce a learning effect. Results indicate that differences in game results over different runs were influenced prominently by factors related to coordination and communication (Table 2) rather than by the recall of the game scenario. This outcome roughly suggests that experiencing the game from the different roles contributed at developing communication abilities and strengthening team cohesion (Figure 2).

Quantitative results (video analysis and game statistics) were first cross-compared, and then compared with qualitative results using Pearson's correlation coefficients. Results show that the ship's average speed is a good factor to infer the Request of Action (RA) among *Crew* members (C2C, $r = 0.75, p = 0.008$), whereas the number of collisions reflects the overall RA on all the communication paths ($r = -0.77, p = 0.086$). A high correlation was found in the number of IS events and the number of tunnel segments nav-

Table 1: *Communication abilities.*

#	Statement	Score
1	To complete the game successfully it was essential to communicate	4.67 (0.47)
2	The game motivated me to find the best way to communicate with the other team members	4.25 (0.82)
3	Having taken on the different roles has been important to understand the other players' perspective on the game	4.58 (0.64)
4	Taking on the other roles helped me to improve my abilities to communicate with the team	4.25 (0.72)
5	Team would have obtained better results by having each player take on the same role all the times	3.08 (1.50)
6	Overall, I think that this game could improve my ability to work in team and to communicate	3.92 (0.64)
7	Reaching the assigned goal was very important for the team	4.33 (0.85)
8	The team worked hard to reach the goal	4.25 (1.09)

Table 2: *Learning effects.*

#	Statement	Score
1	Recall of the path/the map	2.00 (1.08)
2	Knowledge of controls/interactions	4.08 (0.95)
3	Coordination within the team	3.92 (0.76)
4	Familiarity in communicating with the team	4.33 (0.62)
5	Effectiveness of communication	3.92 (0.86)
6	Development of a lexicon/of rules in the team	4.08 (1.08)

igated more than once ($r = -0.54, p = 0.098$). Finally, results indicate that game statistics are quite a good proxy of video analysis data, since there was a medium to high correlation between the communication events and the performance score (N2C = 0.73, C2H = 0.48, C2C = 0.79, overall = 0.76, all with $p < 0.05$).

4. Conclusions and Future Work

This paper presents the design and implementation of a SG enabling a digital team building experience. Preliminary assessment shows that the tool has a promising potential in developing communication interactions and trustiness among members of a forming team. Future work will aim to extend the experimental evaluation to a large number of subjects. Furthermore, changes could be introduced in the design to strengthen the relevance of problem solving (e.g., adding puzzle games) and study other perspectives of communication (e.g., the *Navigator* could be moved "inside" the ship, passing from the current lead/follow to a peer-to-peer approach).

Acknowledgements

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