Building a Game to Build Competencies

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Abstract. Positive developments in aviation, such as the increased safety of air travel, advanced automation and more efficient pilot training courses, may negatively influence the pilots' abilities to handle unknown and unexpected situations. Pilots of the older generation often have experience with manually flying multiple types of aircraft and handling all kinds of incidents. In contrast, the future generation of pilots will not be given the chance to gain the experiences in practice. Consequently, they may not have the competencies needed to handle critical situations. This paper describes how we set about designing a serious game for the acquisition of the essential competencies for critical situations. The game offers meaningful events, which match situations that pilots can face someday. The events trigger and reinforce the competencies of situational awareness, workload management, and application of procedures.

Keywords: Serious games · Zero-fidelity simulation · Aviation Competencies · Critical situations · Meaningful events

1 Serious Games for Aviation Training

Since the introduction of air travel at the beginning of the twentieth century, many advances have been made that have greatly improved the safety of air travel [1]. Aircraft have been made robust, and rules and regulations for air travel have been implemented. Pilot training has become regulated and with the invention of the full flight simulator it has gained in quality and efficiency. The rise of the automatic pilot has also had great effects on the safety. Without any argument, these are positive developments. However, the positive changes may also have a negative side.

Pilots of the older generation often have a background with diverse aviation experiences. Many of them have had a career with a military background or have skills in gliding, aerobatics and other aerospace activities before they started working on large, multi-crew aircraft, building their expertise and preparing them for almost any situation. In contrast, younger airline pilots often take a new, different route to becoming an airline pilot. They start their career in high-tech, modern aircraft with advanced automation, limiting their experience with hands-on, manual flying. They receive extensive training, but they have less hours of flight time when they start their

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airline career, and in many cases they have less flying experience in general. Research shows that, in critical situations, pilots fall back on their prior experience [2].

Yet, in such situations younger pilots do not have the experience on which they can fall back. Of course, we know that in normal situations, and even most non-normal[1] situations, extensive training has prepared pilots to perform their jobs adequately, guided by a large number of procedures and checklists. Still, during a flight *unexpected* situations can occur; i.e., situations that do not match with what the pilots anticipate [3]. When a situation is unexpected, and on top of that, *unknown* to the pilot at work, it could (momentarily) surprise him[2], causing him to lose control of the situation which could then turn into an emergency. We refer to such situations as '*critical situations*'. The actual experience problem may manifest itself primarily in these rare situations.

Obviously, the technical knowledge and skills of a pilot are vital, but in critical situations it may happen that the non-technical competencies are key to handling the problem. The pilot's ability to stay calm, think and act is vital to a successful outcome in an emergency. If the required competencies cannot be gained from actual flight experience, they should be developed through training.

Currently, aviation training uses several training methods, such as (1) computer based training, (2) classroom lectures, and (3) flight simulations [4]. Computer-based training (CBT) was introduced into aviation in the 1980's [5] and is now often used in the theoretical part of the initial pilot training and the recurrent training of licensed pilots, together with lectures. Technical skills are commonly trained in flight simulators. And for the real thing, aspirant pilots usually start flying with a single engine aircraft and gradually work their way up to a large airline jet.

Usually, a certified full flight simulator (FFS) is used in training. An FFS is an identical copy of a particular aircraft cockpit, in both physical shape and behaviour. However, the use of an FFS is costly. The time available should be used for training the principal (technical) skills of the pilots. Cognitive skills and competencies are better trained outside these simulators to save money, and possibly to reach a greater effect. This is not to say that simulations cannot be used for the purpose of training cognitive skills, because there are other types of simulations.

In addition to the more traditional training methods, modern training concepts can be considered to supplement the theoretical and simulation-based training, particularly for the training of non-technical skills. One of these concepts is the use of games as a training tool. This is known as game-based learning or '*serious gaming*'.

Games can be used as a training tool for many kinds of learning goals, such as gaining knowledge or developing competencies [6]. The learning goal affects the design of the game. In a serious game, learning usually takes place implicitly [7]. The learner does not receive direct instruction and may not be aware he is learning while playing the game. The learning is an incidental consequence of playing the game. This '*stealth learning*' [8, 9] is in contrast with traditional training methods in which the transfer of knowledge is explicit and the learning goals are clear in advance.

[1] Although 'abnormal' is the familiar opposite of 'normal', 'non-normal' is the term adopted by aviation regulation bodies such as the FAA, EASA and ICAO.

[2] For brevity, we use 'he' and 'him' wherever 'he or she' and 'him or her' are meant.

The learning effect of a serious game is generally attributed to an increase of intrinsic motivation in learners, leading to more attention and longer Time-on-Task [10, 11]. From other publications, we know that the increased motivation is possibly a result of learning in a meaningful context and learning by doing [12]. Improved learning can also be the effect of social aspects, collaboration and competition [13] and of improved retention and transfer [14]. Combining gameplay with a debriefing session, to make the learning explicit by reflecting on it, adds to the learning effect of the game [15].

To build the competencies needed in critical situations, serious games could provide a meaningful alternative to actual flight experience using a so-called '*zero-fidelity simulation*', i.e., a type of simulation in which the target environment is abstracted and the focus is on the cognitive, human aspects of the tasks [16].

This paper starts with a description of the planned study to measure the transfer of the competencies of situational awareness, workload management and application of procedures from a serious game setting to a pilot's performance in an aircraft (Sect. 2). Then it reports on the design of this serious game that implements meaningful events to acquire the essential competencies for critical situations (Sect. 3). The beta version of the Shuttle to Mars game has been submitted to a playtest (Sect. 4). Finally, we discuss the study (Sect. 5).

2 Measuring the Learning Effect of a Serious Game for Pilots

To measure the extent to which a serious game improves the handling of critical situations, we plan to perform an independent-measures experiment (Fig. 1) with two groups of relatively unexperienced airline pilots, to gather both quantitative and qualitative data. We aim to recruit at least 40 participants, men and women, who will be randomly assigned to one of the two groups. Participants in the test group individually play the serious game, described in Sect. 3. The gameplay will be divided into segments that each contains a number of game levels and is concluded with a questionnaire. The questionnaires will contain questions for the assessment of the player's motivation and engagement, as well as for the purpose of debriefing and reflecting on the learning process [15]. The control group will be briefed about the purpose of the study and the importance of the essential competencies during critical situations, and they will fill out a questionnaire. They do not play the game.

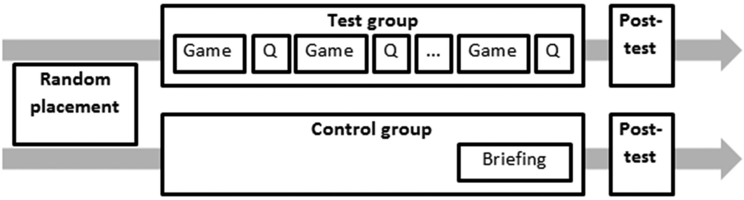

Fig. 1. Serious game transfer experiment procedure

The post-test for each participant will consist of a session in a fixed-base flight simulator for a Boeing 737 aircraft. The participant's performance will be assessed by the examiner focussing on behavioural indicators for the essential competencies.

We expect to see an improvement in the participant's performance during the game (test group) and a difference between the performances of both groups (test and control) in the simulator. This would indicate a positive, transferable learning effect of the serious game. To examine this effect, we will analyse the data coming from (1) the game, (2) the questionnaires, and (3) the assessments made by the examiner in the simulator.

3 Creating Shuttle to Mars

Below, we describe the prototype of a serious game by which the essential competencies for critical situations can be trained. We call this game 'Shuttle to Mars'. In this title, 'Shuttle' refers to the familiarity of a common activity, while 'Mars' appeals to unknown situations and a sense of adventure.

First, the essential competencies that the game will address are identified in subsect. 3.1. Subsequently, we design meaningful events of increasing complexity to create an engaging gameplay and to raise the pilots' level of experience in subsect. 3.2.

3.1 Identifying the Essential Competencies

Airline companies provide their pilots with Standard Operating Procedures (SOP) for a wide range of tasks in normal situations. SOP manuals include many checklists that must be followed in non-normal situations, in which it is not possible to operate the aircraft using the normal procedures.

A non-normal situation is not necessarily an emergency. It may become an emergency when the safety of the aircraft or the persons on board or on the ground is endangered. Non-normal situations happen every day, but rarely result in accidents [17]. Even severe situations do not need to become emergencies, if the pilot acts adequately. The main task of the pilot is to keep control over the aircraft at all times. A safe continuation of the flight must be secured before accomplishing any non-normal checklist or attempting to handle and solve the problem. A pilot needs certain competencies in order to be able to act accordingly.

The International Civil Aviation Organization (ICAO) has provided a list (Table 1) of eight core competencies describing the technical and non-technical knowledge, skills and attitudes that are needed to operate safely, effectively and efficiently in a commercial air transport environment [18].

Table 1. ICAO Core Competencies

1. Application of Procedures (AP)
2. Communication (COM)
3. Aircraft Flight Path Management, automation (FPM)
4. Aircraft Flight Path Management, manual control (FPM)
5. Leadership and Teamwork (L&T)
6. Problem Solving and Decision Making (PS&DM)
7. Situation Awareness (SA)
8. Workload Management (WM)

To determine which of the ICAO competencies are essential in critical situations, we performed (1) a document study, (2) an observation, and (3) a series of interviews. The document study served to find both formal and informal sources on the tasks that a pilot has to perform during normal and non-normal situations. This study yielded scientific articles, public documents, websites and weblogs. In these materials multiple sets of guidelines for handling non-normal situations [19–21] were found. Although the phrasing of the guidelines varies, eleven common guidelines have been identified and matched to the ICAO core competencies (Table 2).

Table 2. Matching common handling guidelines with ICAO competencies

Handling guideline	ICAO competencies
Be aware of changes in situation	7. Situation Awareness
Perform your primary task	1. Application of procedures 3. Flight Path Management, automation 4. Flight Path Management, manual control
Stay calm	8. Workload Management
Identify source of the problem	6. Problem Solving and Decision Making
Determine severity	6. Problem Solving and Decision Making
Come up with a plan	6. Problem Solving and Decision Making
Prioritize duties	6. Problem Solving and Decision Making 8. Workload Management
Delegate duties	8. Workload Management
Use non-normal checklists	6. Problem Solving and Decision Making
Take action	6. Problem Solving and Decision Making
Communicate	2. Communication

A simulator training session in a Boeing 777 FFS was informally observed. The training session consisted of a large number of non-normal situations and emergencies initiated by the instructor/evaluator. The two pilots were scored on communications, performance of technical operations, and their application of procedures and checklists. The way the pilots handled the situations in the simulator corresponded with the handling guidelines (Table 2) found in the document study.

Semi-structured interviews were conducted with four captains and one first officer from several airlines; 4 men and 1 woman. Each interview lasted about 60 min. Their work experience ranged from 15 to 25 years and from 5,000 to 14,000 flight hours. The questions focused on the pilots' backgrounds, their experience with non-normal situations and their view on the essential competencies, based on the ICAO core competencies (Table 1). The interviews confirmed that real emergencies are rare. All pilots had only experienced a few non-normal situations in their careers and they did not consider most of these situations an emergency. They all indicated that flying the plane (competencies 3 and 4) is most important, together with Problem Solving and Decision Making (competency 6), Situational Awareness (competency 7) and Workload Management (competency 8). This is also consistent with the guidelines found in the document study, as shown in Table 2.

Although the study included a small number of interviews and one observation, we believe the findings are valid, based on the methodological triangulation. Therefore, we established here that the following four competencies are essential in critical situations:

1. Situation Awareness
2. Workload Management
3. Application of Procedures
4. Problem Solving and Decision Making

The Shuttle to Mars game will aim to activate these competencies, in order to improve the pilots' ability to act adequately in critical situations.

3.2 Designing the Game

Shuttle to Mars is designed to build the essential competencies needed by airline pilots in critical situations without explicitly telling the players about it [8]. It aims to create a positive attitude toward these competencies and lower the threshold of applying them in their daily jobs. The game is developed as a single-player first-person cockpit adventure for iPad with the Unity 3D platform. It should engage the players and appeal to them to play the game out of their own accord.

The narrative of Shuttle to Mars is set in outer space. This space theme was chosen for the similarities between space travel and air travel, which are distant but still easily recognized by the player. Although the game does not offer a recognizable airplane cockpit and the tasks do not resemble actual piloting, it is in fact a '*zero-fidelity*' simulation of flying a commercial airplane [15]. The individual aspects of tasks and situations in the game correspond with those of flying. Game mechanics are combined into '*meaningful events*'; i.e., complex situations that have a strong link to critical situations in aviation. While composing meaningful events from the game mechanics available, emphasis lies on triggering and reinforcing the essential competencies.

The space theme also allows for a motivating storyline, a continuous primary task, a high workload with secondary tasks, and opportunities for surprising situations.

In the game, the player takes on the role of the captain of a Mars shuttle. His job is to transport cargo through outer space. Each delivery run is presented as a mission (level). The player's goal in each mission is to reach the destination, with as little damage as possible to cargo, crew and spaceship. In order to reach its destination with the highest score possible, the spaceship has to be controlled, resources need to be managed, safe passage through all space sectors has to be arranged and all kinds of situations need to be dealt with. The player needs to stay calm, stay focused and use problem solving skills to succeed.

The complexity of the game increases in the course of the missions. In total the game will comprise twenty missions. The first three missions aim to familiarize the player with the game and the possibilities of the gameplay, and to let him develop some routine in performing the tasks. The rest of the missions serve to help the player reach the learning objective.

Fig. 2. Shuttle to Mars cockpit

The game environment is dynamic and requires much interaction from the player. It contains elements of surprise that aim to throw the player off balance. From his position in the cockpit, the player has a first person view of the dashboard, the overhead panel, the Head Up Display (HUD) and, through the windshield, outer space (Fig. 2). As part of the storyline the player will interact with non-player characters (NPC); two crew members, Galaxy Traffic Control, other spaceships and potential enemies. The player will receive messages, requests and orders through onscreen and audio notifications. He can respond by giving input through a numeric keypad and through buttons, switches and sliders.

The player's primary task is to stay on track and avoid obstacles, along with monitoring the spaceship's status. During each mission meaningful events arise (Table 3) that the player has to respond to and that call upon the essential competencies to be able to perform certain tasks. Notifications and signals must be dealt with in a timely manner to prevent the situation from deteriorating into a catastrophe. Situations range from relatively simple to very complex and difficult to handle.

Table 3. Examples of meaningful events, real life parallels and competencies

Meaningful event	Parallel with real life	Competency
Follow designated route	Routinely perform primary task combined with secondary tasks	FPM
Interactions with NPC	Communicate with several sources, through several media	COM
Authentication call	Perform procedure	AP, WM
System failures	Maintain level of situation awareness, Delegate work	SA, WM
Asteroids on path	Choose best solution	PS&DM
Resource shortages	Maintain level of situation awareness, Balance resources	SA, PS&DM
Pirate encounter	Weigh options	PS&DM
Passing space ships	Maintain level of situation awareness	SA

In critical situations in aviation, complicated incidents are combined with dangerous circumstances and time pressure. The meaningful events in the game mimic this. They are matched, based on four elements: (1) the essential competencies, (2) their behavioural indicators, (3) working conditions and (4) characteristics of the tasks. The parallels created are intended to stimulate transfer of the competencies from the game to the actual work environment. To ascertain relevant parallels, airline instructors are consulted during the design of the meaningful events.

4 Playtesting the Game

The beta version of Shuttle to Mars was submitted to a playtest. The purpose of a playtest is to determine whether the game produces the experience which the designers intended to reach [22]. A playtest also identifies pacing and balancing problems [23]. In usability studies, a sample of five users will identify almost as many problems as a larger group [24]. For a serious game, playtesting is done to determine whether the target audience will be engaged in the game. Without engagement, the educational objective will not be reached. Furthermore, playtesting provides information as to whether the game controls are understandable and tractable, and the game is playable for the target group. The game's functionality and technical quality are not tested in a playtest [22].

Five male participants played Shuttle to Mars; four airline pilots and one flight simulator engineer. They played selected parts of the game, and were asked to think aloud during the entire playtest. The playtest was directed by a supervisor and observed by two observers. Video and audio recording were made and the iPad screen was captured. During the playtest the supervisor asked questions about the player's behaviour in the game, when the participant had completed a mission.

Before and after playing the game, the participants were interviewed and they filled out a questionnaire with 21 questions using a five-point scale. Nine questions were aggregated into subgroups regarding four important topics: (1) controls, (2) enjoyment, (3) engagement, and (4) parallels with reality. The results (Fig. 3) show that the game controls were understandable and tractable. Moreover, the participants enjoyed the game. They became engaged in the game and tried to succeed. All participants acknowledged the parallels between the space-themed storyline and aviation reality. The outcomes correspond with the participants' commentaries during the test. On top of that, three of the four airline pilots spontaneously identified the competencies which the game aims to reinforce.

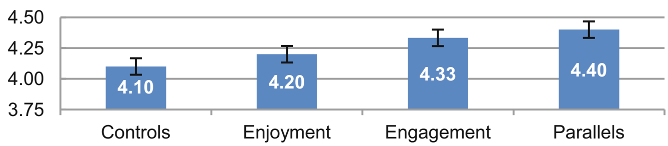

Fig. 3. Questionnaire results (five point Likert scale, means with standard errors)

The playtest was aimed at establishing the playability of Shuttle to Mars, not at finding statistical proof of its learning effect. The outcomes of the playtest give us confidence that Shuttle to Mars will be fun to play and will possibly have a positive learning effect. More missions will be designed to provide learning through meaningful events. With the completed game we will have a second playtest with another five participants. That playtest will focus on the quality of the game data, but will also provide insight into the appreciation of the gameplay. Afterwards, we will move forward to examine the learning effect and the learning transfer in the experimental setup (see Sect. 2).

5 Discussion

The goal of professional training is to improve performance in the actual work setting. The behaviour, knowledge and skills acquired in a specific training environment must be transferred to situations in a different, real world environment [25]. Transfer of learning from a training situation to a working context is hard to prove. In case of handling critical situations in aviation, proving it is even impossible due to safety and ethics. Obviously, sending pilots up in the air and creating a critical situation to see how they fare is ethically unacceptable. However, training in a flight simulator is safe, and the transfer from flight simulator to cockpit has long been acknowledged [26]. Therefore, we resort to an experiment involving a flight simulator. We will look for evidence that the Shuttle to Mars game has a positive effect on the adequate handling of a critical situation in the flight simulator, as an indication that it will also have a positive effect on the pilot's performance in the actual aircraft.

The game data will provide information about the player's performance, including response times, correct answers, and procedures followed. We expect that the participants will get better at handling the meaningful events as they spend more time playing the game. The game data is connected to behaviour indicative of the essential competencies. The questionnaires will provide information about (1) the participant's motivation during the gameplay, (2) his engagement in the game, and (3) his understanding of the learning objectives and the relevance of the game. As an active, positive attitude is beneficial for the learning effect [27], the questionnaires continuously monitor the participants' engagement and motivation levels.

We expect to see a stronger improvement in simulator performance by the game playing participants in comparison to the control group. Such a difference may indicate that playing the game improves the player's ability to handle critical situations in the simulator, and consequently improve performance in the work environment.

The Shuttle to Mars prototype has the potential of becoming an effective training (research) tool. Before the experiment starts, some improvements need to be implemented. The game levels need to be filled with meaningful events that allow the building of the essential competencies. When a final playtest is successful, the experiment can be performed to examine the learning effect and to what extent this learning transfers from the game to the work environment.

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