Building a game to build competencies

Esther Kuindersma[1 (✉)], Jelke van der Pal[1], Jaap van den Herik[2] and Aske Plaat[2]

[1] Netherlands Aerospace Centre (NLR), Amsterdam, The Netherlands
Esther.Kuindersma@NLR.nl
[2] Leiden University, Leiden Institute of Advanced Computer Science, Leiden, The Netherlands

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 will not have the competencies needed to handle critical situations. This paper reports on acquiring the essential competencies for critical situations with a serious game. The game offers meaningful events, which match events that pilots may someday experience. 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 Introduction

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 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]. However, in such situations younger pilots do not have the experience on which they can fall back on. In normal situations, and even most non-normal situations, the extensive training has prepared pilots to perform their jobs adequately, guided by a large number of procedures and checklists. However, during a flight *unexpected* events may happen; i.e., events 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 may (momentarily) surprise him[1], causing him to lose control of the situation which may 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.

Of course, the technical knowledge and skills of a pilot are always vital, but in critical situations it may happen that the non-technical competencies are crucial to handling the problem. It comes down to the pilot's ability to stay calm, think and act. If the required competencies cannot be gained from actual flight experience, they should be developed through training.

This paper starts with some background on the application of serious games for aviation training (Section 2). Then it reports on the design of a serious game to raise the level of experience of future generation pilots (Section 3) and describes an experiment to measure the transfer of competencies from the game to the aircraft (Section 4). Finally, we formulate some concluding remarks (Section 5).

2 Serious games for aviation training

Currently aviation training makes use of several training methods. Among them are (1) classroom lectures, (2) computer based training, and (3) flight simulations [4].

Lectures and computer-based training (CBT) are often used in the theoretical part of the initial pilot training and the recurrent training of licensed pilots. 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. CBT was introduced into aviation in the 1980's [5] and has now become an integral part of many training courses. There are many providers of CBT and it has been recommended and guided by international aviation agencies.

Usually, a certified full flight simulator of a particular aircraft type is used in training. A full flight simulator is an identical copy of the actual aircraft cockpit, in both physical shape and behaviour. However, the use of these full flight simulators is costly. The time available should be used for training the essential (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*'.

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

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.

The learning effect of a serious game is generally attributed to an increase of intrinsic motivation in learners, leading to higher attention and longer time on task [10]. The increased motivation may be a result of learning in meaningful context and learning by doing [11]. Improved learning may also be the effect of social aspects, collaboration and competition [12] and of improved retention and transfer [13]. Combining gameplay with a debriefing session, to make the learning explicit by reflecting on it, adds to the learning effect of the game [14].

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 [15].

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'. First, the essential competencies that the game will address are identified (Subsection 3.1). Then, we design a simulation game aiming at engagement and stealth learning (Subsection 3.2). Subsequently, a playtest is conducted to assure the playability of the game (Subsection 3.3). Finally, the game levels are endowed with meaningful events of increasing complexity to create gameplay (Subsection 3.4).

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 [16]. 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 time. 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 [17].

Table 1. *ICAO Core Competencies*

1. Application of Procedures
2. Communication
3. Aircraft Flight Path Management, automation
4. Aircraft Flight Path Management, manual control
5. Leadership and Teamwork
6. Problem Solving and Decision Making
7. Situation Awareness
8. Workload Management

We performed a Cognitive Task Analysis (CTA), consisting of (1) document study, (2) observation, and (3) interviews, to determine which of the ICAO competencies are essential in critical situations. CTA is aimed at understanding tasks that require many cognitive activities from the performer. CTA applies several methods for collecting information on the knowledge, skills and cognitive processes that form the basis of observable behaviours when performing certain tasks [18].

A document study was performed 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, 20, 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).

A simulator training session in a Boeing 777-simulator 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.

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

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 minutes. Their work experience ranged from 15 to 25 years and from 5,000 to 14,000 flight hours. The questions focussed on the pilots' background, their experience with non-normal situations and their view on the essential competencies, based on the ICAO core competencies (Table 1). From the interviews, we learned that real emergencies are rare. Each of the interviewees had only experienced a few non-normal situations in their careers and they would not consider most of these situations an emergency. The pilots all indicated that flying the plane (Competency 3 and 4 Flight Path Management) is most important, together with Problem Solving and Decision Making (Competency 6), Situational Awareness (Competency 7) and Workload Management (Competency 8). This is consistent with the guidelines found in the document study, as shown in Table 2.

The CTA resulted in the determination that four competencies are essential in critical situations. These competencies are:

1. Situation Awareness
2. Application of Procedures
3. Workload Management
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

In Shuttle to Mars, 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). In total the game will comprise of approximately twenty missions. 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 events need to be dealt with. The player needs to stay calm, stay focused and use problem solving skills to succeed.

Shuttle to Mars is designed as a single-player first-person cockpit adventure game. It is developed for iPad with the Unity 3D platform. The game is intended to be played by airline pilots. It should engage the players and appeal to them to play the game out of their own accord. We opted for a single-player design, because playing with peers may prove problematic. As airline pilots travel around the world, their co-workers may be in different time zones.

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 simulation of flying a commercial airplane [15]. The individual aspects of tasks and situations in the game strongly correlate to those of flying. The space theme also allows for a motivating storyline, a continuous primary task, a high workload with secondary tasks, and opportunities for surprising events.

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. The game is designed to build the essential competencies needed by 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.

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. 1). As part of the storyline the player will interact with other (non-player) characters; 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.

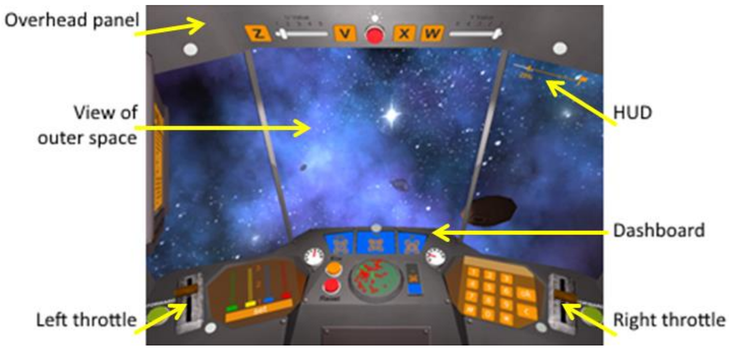

Fig. 1. Shuttle to Mars cockpit

The player's primary task is to stay on track and avoid obstacles, along with monitoring the spaceship's status. The speed of the spaceship is automatically controlled. During each mission all kinds of situations (Table 3) emerge that the player has to respond to and that require him to perform certain tasks. All 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 game events and connected responses*

Event	Response(s)
Asteroids	Evade
Authentication call	Perform procedure
Fuel shortage	Trade resources for fuel
Passing space ship	Answer question from crew
Pirate encounter	Negotiate, fight
System failure	Perform reset to fix, delegate fix to crew

During the game, the situations will build up to '*meaningful events*'; i.e., complex situations that have a strong link to critical situations in aviation. They combine complicated events with dangerous circumstances and time pressure. The parallels created with these events, are intended to stimulate transfer of the competencies from the game to the actual work environment.

3.3 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 the designers intended [22]. It also identifies pacing and balancing problems [23]. For a serious game, playtesting is done to determine if 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 clear 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. Before and after playing the game, the participants were interviewed and filled out a questionnaire. During the playtest the supervisor would ask questions about the player's behaviour in the game, when the participant had finished playing.

The playtest showed that the game controls are clear and that the players enjoy the game. They become engaged in the game and try their best to succeed. All participants acknowledged the parallels between the space-themed storyline and aviation reality. Three of the four airline pilots spontaneously identified the competencies the game aims to reinforce. Based on this outcome, we believe that Shuttle to Mars can have a positive learning effect on airline pilots. More missions are designed to provide meaningful events. Then we will move forward to examine the learning effect and the learning transfer in an experimental setup.

3.4 Creating meaningful events

The next step in the design process is the creation of meaningful events in the Shuttle to Mars storyline. These events are a part of the missions. The meaningful events are matched to critical situations, based on four elements (see Fig. 2): (1) the essential competencies, (2) their behavioural indicators, (3) working conditions and (4) characteristics of the tasks. To ascertain relevant parallels, airline instructors are consulted during the design of the meaningful events. While composing meaningful events from the basic elements available in the game, emphasis lies on triggering and reinforcing the essential competencies.

The complexity of the meaningful events increases in the course of the missions. The first missions aim to make the player familiar with the game and the possibilities the gameplay offers, and to let the player develop some routine in performing the tasks. The later missions serve to develop the desired behaviour and with that, build the essential competencies for critical situations.

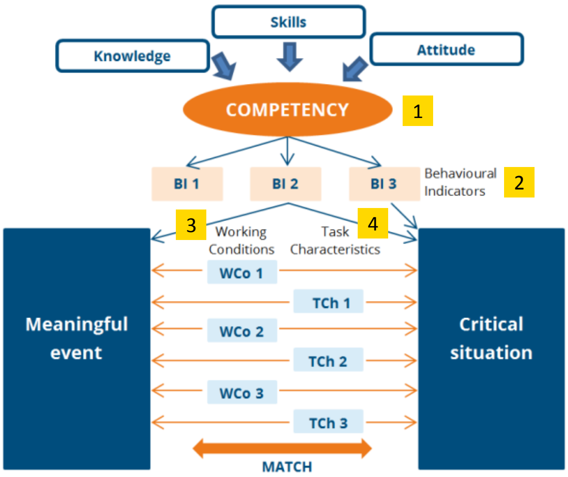

Fig. 2. Matching meaningful events with critical situations

4 Future research: Measuring transfer from game to aircraft

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 [24]. Transfer of learning from a training situation to a working context is hard to prove. In case of handling critical situations in aviation, it is even impossible due to safety and ethics. It is out of the question to send pilots up in the air and create a critical situation to see how they fare. However, training in a flight simulator is safe, and the transfer from flight simulator to cockpit has long been acknowledged [25]. 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.

We plan to perform an independent-measures experiment (Fig. 3) with two groups of relatively unexperienced airline pilots, both men and women. We aim to recruit at least 20 participants per group. Participants in the test group individually play the Shuttle to Mars game, as described in Section 3. The game play will be divided into segments. Each segment will contain a number of game levels, and is concluded with a questionnaire. The questionnaires are under development, and 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 [14]. The participant receives a code to continue on to the next segment when each questionnaire is completed. 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.

Each participant's performance in the simulator post-test will be assessed by the examiner focussing on behavioural indicators for the essential competencies.

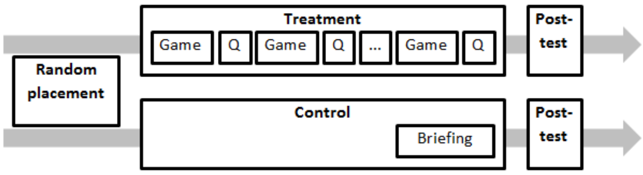

Fig. 3. Shuttle to Mars transfer experiment procedure

We expect the Shuttle to Mars game to have a positive, transferable learning effect. To examine this effect, we will analyse the data coming from (1) the game, (2) the questionnaires, and (3) the observations made by the examiner in the simulator. Improvements in the game data will indicate that, as the participants spend more time playing the game, they get better at handling the meaningful events. The game data is connected to behaviour indicative of the essential competencies. The questionnaires will provide information about the participant's motivation during the treatment and his engagement in the game. It will also offer data about the participants understanding of the learning objectives and the relevance of the game. From the questionnaires we hope to see that the participants are, and remain, engaged in the game and are motivated to play. An active, positive attitude is beneficial for the learning effect [26].

We hope to see a significant difference in the participants' performance between the test group and 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.

5 Concluding remarks

The Shuttle to Mars prototype has the potential of becoming an effective training tool. More work is needed to fill the game levels with meaningful events that allow the building of the essential competencies. In addition, further research is needed once the game is completed, to examine the learning effect and to what extent this learning transfers from the game to the work environment.

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