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Cleared for take-off: Game-based learning to prepare airline pilots for critical situations

Kuindersma, E.C.

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Author: Kuindersma, E.C.

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Chapter 5

Creating Shuttle to Mars: a game to provide experience

In this chapter, we will discuss the preparations that we have made to be able to answer RQ 3. The preparations contain the design and development of the *Shuttle to Mars* game.

RQ 3: *To what extent do airline pilots accept a game to develop essential competencies for critical situations?*

The natural start of our research in this chapter is determining what competencies the *Shuttle to Mars* game would aim to train. In Section 5.1, we will identify the competencies that are essential for airline pilots to act adequately in critical situations. In Section 5.2, we will describe the important ins and outs of the *Shuttle to Mars* game. Next, in Section 5.3, we will elaborate on the design of the *Shuttle to Mars* game, based on our SG4CD model. The game is intended to be fun as well as instructive, as it should keep the player playing and reach the learning objective at the same time. After the analysis in Section 5.2 and the design discussed in Section 5.3, the game has been developed and tested in Section 5.4. There, we will playtest, analyse, and discuss the outcomes of the test. The outcomes of this test will be taken as conditions for the further development of the *Shuttle to Mars* game. Finally, in Section 5.5, we will give our conclusions about the design and development of our serious game. They will be collected as the preparations for answering RQ 3. RQ 3 itself will be answered in Chapter 6.

The contents of this chapter are based on the following two publications:

1. Kuindersma, E. C., van der Pal, J., van den Herik, H. J., & Plaat, A. (2016b). Shuttle to Mars: Training airline pilots for critical situations. Poster and handout presented at the Meaningful Play Conference. East Lansing, MI.
2. Kuindersma, E. C., van der Pal, J., van den Herik, H. J., & Plaat, A. (2017). Building a game to build competencies. In J. Dias, P. A. Santos & R. C. Veltkamp (Eds.), *Games and Learning Alliance, 6th international conference* (pp. 14-24). Heidelberg, Germany: Springer.

5.1 Competencies for critical situations

In Chapter 2, we have described and defined the terms *airline pilots* (see Definition 2.1), *competencies* (see Definition 2.6) and *critical situations* (see Definition 2.5). In this section, we will identify the competencies that airline pilots need in critical situations.

In Subsection 5.1.1, we will look at the ICAO core competencies that all airline pilots are expected to possess. Next, we will identify which competencies are essential in critical situations. To do so, we have performed a job analysis (Subsection 5.1.2).

5.1.1 Airline pilot competencies

The eight core competencies, identified by ICAO, the IATA and the IFALPA, are divided into behavioural indicators (see Appendix C.2) that describe the technical and non-technical knowledge, skills and attitudes that are needed to operate safely, effectively and efficiently in a commercial air transport environment [129, 207].

At any time during a flight, the main task of the pilot is to keep control over the aircraft. A safe flight path must be ensured before accomplishing any non-normal checklist or attempting to solve any (potential) problem. In non-normal situations, pilots may be surprised. The natural tendency of human beings to life-threatening situations is to fight, flight or freeze [119]. For pilots, this tendency often means that they tend to take actions right away instead of taking the time to assess the situation. However, only a few situations require immediate action. Even severe situations do not need to become emergencies if the pilots act adequately.

To cope with critical situations, pilots need (1) the knowledge and psychomotor skills of manually flying an aircraft under non-normal conditions, (2) cognitive skills such as problem-solving and decision-making, and (3) stress management skills. Our research focuses solely on cognitive tasks.

In the following section, we will identify which cognitive tasks are essential in critical situations.

5.1.2 A job analysis to identify the essential competencies

Keller et al. [103] have described the pilot tasks to include visual, auditory, cognitive, and psychomotor elements. These tasks can be translated into the required competencies and their corresponding behavioural indicators. To determine which of the ICAO core competencies are essential in critical situations, we performed a job analysis. Below, we discuss (A) the methodology, (B) the outcomes and (C) the results of the job analysis.

A. Methodology

We apply a partial job analysis that includes cognitive task analysis elements. Cognitive task analysis is aimed at understanding tasks that require many cognitive activities from the performer, such as problem-solving, decision-making, memory, attention and judge-

ment. Cognitive task analysis applies several methods for collecting information on the knowledge, skills, and cognitive processes that form the basis of observable behaviours when performing specific tasks [175].

We used three methods, viz. (A1) document study, (A2) observation, and (A3) semi-structured interviews, to determine which of the ICAO core competencies are essential in critical situations.

- A1. Document study.** The document study was aimed at finding both formal and informal sources on the tasks that a pilot has to perform during normal and non-normal situations. The document study yielded scientific articles, public documents, websites and weblogs. Attention was paid to non-scientific materials, as relatively few scientific articles are published about the airline pilot's job. Additionally, the references in the articles retrieved were used to find other relevant sources.
- A2. Observation.** The observation was informal. It was performed in a Boeing 777 full flight simulator. Two captains were observed during a simulator training session, that was part of a series of twelve. The training was aimed at the captains qualifying for their type rating (i.e., licence) for Boeing 777. The simulator session consisted of non-normal situations and emergencies initiated by the instructor/examiner. During the session, the captains switched roles and seats a number of times. One of them would take on the role of captain, and the other would play the role of first officer. Thereafter, the roles reversed. The pilots were scored on (1) communications, (2) performance of technical operations, and (3) their adherence to procedures and checklists.
- A3. Interviews.** Interviews were conducted with four captains and one first officer from two different airlines: 4 men and 1 woman. They were all experienced airline pilots, with their experience ranging from 15 to 25 years, and from 5,000 to 14,000 flight hours. The interviews were semi-structured (see Appendix C). The questions addressed the pilot's background, experience with non-normal situations and view on the relevant competencies, based on the ICAO core competencies. Each interview lasted about 60 minutes.

B. Results

The three methods that we applied have yielded the following results.

- B1. Document study.** During every non-normal situation, the primary task of the pilots is to fly the aircraft. The document study, the observation and the interviews all corroborate this view.
A safe flight path must be ensured before accomplishing any non-normal checklist. The pilots should focus on communication and flight path management. The pilot who has control over the aircraft must focus on stabilising the aircraft and call out immediate actions. The other pilot will accomplish these actions and start the appropriate checklist [82]. Pilots should sit on their hands for a moment to stay calm and let the shock subside [98].

In non-normal situations, pilots may have to deal with surprise or startle [185]. In actual emergencies, pilots may suffer from stress and panic. They will experience an increased workload and stress. In non-normal situations and emergencies, there may be additionally complicating factors (such as cognitive limitations, choices with uncertain outcomes, and time pressure) [125]. Teamwork and leadership are important in handling a non-normal situation correctly [64].

In the document study, we compared several sources [82, 98, 148] on how to handle non-normal and emergency situations. Each source provides its own guidelines. Although the phrasing of the guidelines varies, we identified eleven common guidelines and linked them to the ICAO core competencies (see Table 5.1).

Table 5.1: Combining handling guidelines with ICAO core competencies

Handling guideline	ICAO core competencies
Be aware of changes in situation	7. SA
Perform your primary task	1. AP 3. AFPM-A 4. AFPM-M
Stay calm	8. WM
Identify the source of the problem	6. PS&DM
Determine severity	6. PS&DM
Come up with a plan	6. PS&DM
Prioritise duties	6. PS&DM
Delegate duties	8. WM
Use non-normal checklists	1. AP 6. PS&DM
Take action	5. L&T 6. PS&DM
Communicate	2. COM

B2. Observation. The pilots observed in the simulator training session had extensive experience in different types of aircraft. As a result, they were familiar with all situations and procedures. Only small variations in the design of the cockpit and the behaviour of the aircraft make the observed training different from their previous experiences. The pilots were also aware that they were in a training session and that a large number of different situations would be offered. They may have been hardly surprised at all by the events, as they are "on the edge of their seat" and highly vigilant. The captains showed good situation awareness and communication. Only once, there was some surprise as one of the three screens of the flight management system malfunctioned. For one second, they did not know how to access the information without this screen, but then they quickly found a workaround by using one of the other screens. This is only one example of problem-solving and decision-making. It serves as an idea generator for other situations that need a fast reaction or a creative solution.

The way in which the pilots handled the situations in the simulator corresponded with the handling guidelines (Table 5.1) found in the document study. The pilots might hear an alarm or notice a deviation in the systems, and then they would find out what could be the cause of the problem, while still operating the aircraft. They would communicate and divide tasks between them.

B3. Interviews. For the interviews, we invited five pilots connected to NLR. We did not select them on their experience with critical situations. 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. They also indicated that although following procedures is essential in aviation, a pilot is allowed to turn to creative solutions if necessary. This may happen if the pilot believes it to be a better way to prevent or resolve an emergency, or when following the procedures might create a harmful situation.

The pilots selected the ICAO core competencies that they considered essential in critical situations and subsequently ranked their selection. We take into account only the competencies that were selected by at least three of the pilots to be essential competencies. They all agreed that PS&DM (Competency 6) is important. All five pilots selected this competency, and it received the highest average ranking. Furthermore, flying the plane (Competencies 3 and 4: Aircraft Flight Path Management) was identified, together with SA (Competency 7). Only two pilots selected WM (Competency 8), but on top of that, both of them gave it the highest possible ranking. Therefore, we do consider it an essential competency. The selection of PS&DM, AFPM-A, AFPM-M, SA and WM corresponds with the handling guidelines found in the document study (Table 5.1).

C. Conclusion

Both the document study and the interviews confirmed that real emergencies are rare. However, non-normal and even critical situations do occur. The job analysis has led to the selection of three competencies that we consider most important in critical situations.

- Problem-Solving and Decision-Making
- Situation Awareness
- Workload Management

Based on the outcomes of our analyses, we identified a total of 14 behavioural indicators that are relevant within the setting of the *Shuttle to Mars* game. In Appendix C.2, the selected behavioural indicators have been marked with *. These competencies and behavioural indicators will form the basis for the meaningful events in the *Shuttle to Mars* game.

Aircraft Flight Path Management, both Automation and Manual, was identified by the airline pilots as important in critical situations. These competencies are closely related to the primary task of airline pilots and, therefore, they are related to their technical skills. Developing these skills is outside the scope of our research. However, we do address the cognitive aspects of these competencies in our game, by using a recognisable primary task that needs to be performed continuously.

5.2 The Shuttle to Mars game

As no off-the-shelf game was available by which the complete set of identified essential competencies could be trained, a prototype game had to be developed for this specific purpose. We did so by developing a serious game that we call *Shuttle to Mars*. In this title, *Shuttle* refers to the familiarity of a common activity, whereas *Mars* appeals to unknown situations and a sense of adventure. In the design, we aimed to create gameplay that engages the players and appeals to them to play the game out of their own accord.

The work we have done with the *Shuttle to Mars* game has been carried out with beta versions, which we will describe in Subsection 5.2.1. Then, we will give a general description of the game in Subsection 5.2.2.

5.2.1 Beta versions

Shuttle to Mars was designed by the author of this thesis and developed by a team of undergraduate students in Game Technology from Utrecht University as their bachelor project. The game was developed using the Unity 3D platform.

Initially, the game was developed for iPad. The iPad was the device of choice because many airline pilots own an iPad, and it is easy to bring along on flights. Moreover, the iPad is commonly used for casual gaming, and using an iPad to play a serious game may contribute to the appeal of that game.

During the technical realisation of the *Shuttle to Mars* game, it proved unfeasible to build it entirely as it was designed. To meet the deadlines, we had to decide to leave several features and functions out of the beta versions of the game. Many of the features and functions that were omitted, were mentioned by the participants as suggestions for improving the game (see also Subsection 5.5.2).

The playtest (see Section 5.4) was performed with an early beta version of the *Shuttle to Mars* game on iPad. We will refer to this version as *Beta 1*.

After the playtest, during the further development of the game, technical issues arose, making the use of iPads impossible. For that reason, the game was recompiled to be played on a personal computer. The study described in Chapter 6 was performed with the *Shuttle to Mars* game on laptops. It was still a beta version of the game, but in a later stage than the version used for the playtest. We will refer to this version as *Beta 2*.

5.2.2 Game description

In this subsection, we will give an overview of the game design. We will describe (A) the storyline, (B) the game environment, and (C) the tutorial and levels of the game.

A. Storyline

In *Shuttle to Mars*, the player takes on the role of the captain of a Mars shuttle, transporting cargo through outer space. The player's job in each mission is to navigate the spaceship safely to its destination to deliver the cargo. The player must protect the cargo, the crew and the spaceship against damage and loss. To reach the destination with the

highest score possible, the player has to perform multiple tasks: the spaceship has to be controlled, resources need to be managed and supplemented, 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.

As a part of the story, the player will interact with non-player characters: two crew members, Galaxy Traffic Control, other cargo- and passenger spaceships, and potential enemies. Messages, requests and orders are received through on-screen notifications or audio calls. All notifications and signals must be dealt with in a timely manner to prevent the situation from deteriorating into an emergency.

B. Game environment

From his position in the cockpit, the player has a first-person view of (1) the overhead panel, (2) the head-up display (HUD), (3) the dashboard, and (4) outer space (see Figure 5.1). The player gives his input through a numeric keypad, and buttons, switches and sliders.

The speed of the spaceship is automatically controlled, but the player is responsible for keeping the spaceship on the designated path through space. He must steer his spaceship, using the (5) left and (6) right throttles (see Figure 5.1), to avoid obstacles.



Figure 5.1: Shuttle to Mars screenshot: cockpit

C. Tutorial and levels

The Beta 2 version of the *Shuttle to Mars* game consists of a tutorial and fifteen game levels.

Tutorial. When a player first plays the game, he can only start with the tutorial. In the tutorial, the player is guided through his first *Shuttle to Mars* mission. On-screen instructions (for an impression, see Figure 5.2) explain what the player has to do, how to do it and what to expect from the *Shuttle to Mars* missions.



Figure 5.2: Shuttle to Mars screenshot: on-screen instructions in tutorial

The player needs to follow the instructions given in order to proceed through the tutorial. The player receives feedback when completing the actions. By doing so, he explores how the spaceship is operated and what rules apply in the game.

Levels. After the tutorial, the player can continue to the next, unguided mission. In the Beta 2 version, there are fifteen levels. The levels become available in a fixed order to create a sequence with increasing complexity. Once all fifteen levels have been played, all levels become available for replay.

At the start of each level, the spaceship is intact and supplied with resources, such as fuel and ammunition. Each level consists of two or more space sectors through which the player must travel to reach his destination. The player plans his journey by clicking each leg of the journey on the space map. One unit of fuel is needed for each leg. At the end of the sector, the player will have to cross a border. Based on his performance in the sector, he may have to buy resources or pay additional taxes.

The designated flight path of the spaceship is shown as a blue bubble trail (see Figure 5.3). Staying on course and avoiding obstacles are the player's primary tasks in combination with monitoring the spaceship's status.

During a mission, the player will run into a variety of situations. Events will occur that the player has to respond to, and that may require him to perform specific tasks. For example, an asteroid field will force the player to change his course, and a nebula will force him to use his radar instead of the view from the cockpit. In total, fourteen different events may occur (see Table 5.2). At first, the situations will be relatively simple, and only one event will happen at a time. Later on in the game, the events become more difficult. Moreover, situations become more complex as events occur close together or even simultaneously. The situations may become very complex and difficult to handle, combining events requiring complicated tasks in combination with dangerous circumstances and time pressure.



Figure 5.3: Shuttle to Mars screenshot: flight path shown as blue bubble trail

The challenges in the game will build up to meaningful events that have a strong link to the actual situations that a pilot may encounter in his job. The parallels created with these events are intended to stimulate transfer of the competencies from the game to the actual work environment. This will be discussed in more detail in Subsection 5.3.2.

The level is finished when the player succeeds in bringing the spaceship to its destination. The level ends if a player runs out of fuel or his spaceship is destroyed. The player only has one chance to perform well in a game level. The levels cannot be replayed immediately to prevent the player from practising and finding shortcuts.

Table 5.2: Shuttle to Mars events

Primary task	System failures	Obstacles	Encounters	Orders
Plan journey	Fuel meter	Asteroid field	Passing ship	Enter authorisation code
Follow flight path	Headlight	Large asteroid	Pirate attack	Push button when light is on
Steer spaceship	Hull meter Radar Steering Weapon system	Nebula		

5.3 Game design based on the SG4CD model

In Chapter 3, we have introduced the SG4CD model. This model provides guidelines on how to design serious games for competency development. The characteristics that support competency development are connected to the elements that are needed in a serious game to make it a successful game and an effective learning method.

In Subsection 5.3.1, we describe how we have designed the *Shuttle to Mars* game to support the characteristics for competency development. In Subsection 5.3.2, we will discuss the design of meaningful events in the *Shuttle to Mars* game. The meaningful events provide the authentic learning tasks needed for competency development.

5.3.1 Designing the elements of Shuttle to Mars

We will first describe how the game design addresses (A) the game elements and the internal learning elements, (B) the external learning elements, and (C) the characteristics for competency development. The elements that have a purpose both for gameplay and learning are marked with *.

A. Game elements and (internal) learning elements

Non-linearity. The game consists of missions that have to be played in linear order. Within a mission, a player can choose his own route. The routes may differ in difficulty or cost. This feature was designed but omitted in the beta versions (see also Subsection 5.2.1).

Players. A single-player game design was chosen to enable the game to be played at any time. As airline pilots travel around the world, their co-workers have different work schedules and may be in different time zones. Therefore, an airline pilot may be unable to find a co-worker to play with, as a partner or an opponent, at the time he wishes to play the game.

Theme. We have chosen a space game to have a connection to aviation, but with room for fictional elements. In both *worlds*, the tasks are connected to transportation, such as navigating, dealing with threats and dilemmas (e.g., the balance between time and cost). Within the space theme, there can be all kinds of surprising events that aim to throw the player off balance.

Levels.* Each level of *Shuttle to Mars* consists of a mission in which the player starts with a fully functional spaceship and a supply of resources. The missions are played in a fixed order, with the complexity and difficulty of the missions gradually increasing. In the Beta 1 version, two missions were implemented, the Beta 2 version had fifteen missions. A final version will even need to have a larger number of missions.

Genre.* *Shuttle to Mars* is an adventure game. This genre is often used for serious games.

Reality.* The level of reality is low. The game does not offer a recognisable aircraft cockpit, and the tasks do not resemble actual piloting, but the individual aspects of tasks and situations strongly correlate to those of flying. The game is designed to prepare airline pilots for critical situations during flights. Operating the spaceship is not like flying an aircraft, but interruptions and distractions occur in the game as well as in reality.

Narrative.* *Shuttle to Mars* has a space-themed narrative that allows for (1) a motivating adventure, as well as for (2) a continuous primary task, (3) a high workload with secondary tasks, and (4) opportunities for surprising events.

Rules.* A set of rules guides the game. For example, the weapon can only be fired when at least one crew member staffs it. More tax must be paid if the weapon has been fired. Colliding with asteroids will damage the spaceship. Procedures must be followed to the letter to be successful. Some rules have been omitted in the beta versions of the game.

Goals.* The player's job is to bring cargo to a destination. The goal of each mission is to reach the destination. Otherwise, the player will lose the mission. However, a player can set additional goals for himself, such as arriving at the destination with as much cargo as possible, with as many resources, or with as little damage as possible.

Rewards.* No rewards are given in the game. However, some penalties will be given upon the use of undesired behaviours, such as using the weapon or not responding to an authorisation call.

Feedback.* The game offers feedback through the game score. In the design, we planned to provide feedback to the player on how he is doing and how he can improve his score. However, in the beta versions, this was not implemented, and due to technical issues, the score is not presented to the player.

Assessment. Creating an assessment based on game data, such as answers and reaction speed, is possible. However, in the beta versions of the game, implementation of assessment was not completed.

Learning content. The learning content of *Shuttle to Mars* relates to the development of the competencies. This is embedded in the gameplay. By handling the game events, the player uses and strengthens the competencies of PS&DM, SA, and WM.

B. External learning elements

The external learning elements, which are part of the SG4CD model, provide instructional support but are not part of the game. Therefore, they are not addressed in the *Shuttle to Mars* game design. However, instructional support elements contribute to the learning effect. They are offered outside the game, in support of the game. They should be considered when making a plan for implementation of the game in a curriculum.

Collaboration. Collaboration is not directly relevant to *Shuttle to Mars* as it is a single-player game. However, there are ways to incorporate collaboration into the use of *Shuttle to Mars*. For example, players may work together and discuss how to handle the situations. In the current beta versions, no collaboration has been incorporated.

Briefing. Before gameplay commences, the airline pilots can be briefed about the game by the instructor. The instructor can identify the learning objective of the game and the competencies involved. As an *advance organiser* [68], this will focus the attention of the players to the relevant actions, which may result in a stronger learning effect.

Reflection. After playing (parts of) the game, reflection helps the player to focus on the learning content of the game. Players can reflect on how they handled a situation. They can compare their actions with those of other pilots or with the optimal solution presented by the instructor.

C. Characteristics for competency development

The third part of the SG4CD model consists of the characteristics for competency development. In the *Shuttle to Mars* game, we have addressed these characteristics as follows.

Sequencing. The missions in the *Shuttle to Mars* game are sequenced in increasing complexity and difficulty. The player starts with simple, straightforward missions. Gradually, more complex events are presented to the player.

Strengthening routine aspects. Particular actions, such as repairing the radar or the steering, need to be performed repeatedly. This leads to automation of these tasks, which diminishes cognitive load and frees up cognitive capacity for other tasks. Furthermore, the gameplay requires the player to be alert to changes in the situation, thus strengthening the routine task of scanning the instruments.

Authentic learning tasks. Each mission contains several meaningful events that provide authentic learning tasks. The design of meaningful events is discussed in more detail in Subsection 5.3.2.

Conditions. Tasks need to be practised in different situations and under different conditions. The game provides a variety of working conditions and complexity factors such as visibility, time pressure, multitasking, and distractions. The situations are varied to make the gameplay diverse and surprising. In contrast, the conditions and complexity factors are not varied, but they are sequenced to provide an increasing level of difficulty.

Support and feedback. Support and feedback keep a low profile in the game. Support is offered only to keep the player in the game. Feedback is provided through the game score.

Integrated knowledge. A choice was made not to include explicit knowledge or learning content in the game. The game does not provide explanations on how, or why, a task should be performed. The feedback on the player's action gives sufficient support for implicit learning. This learning can be made more explicit through instructional elements, such as briefing and reflection.

5.3.2 Meaningful events

In critical situations in aviation, complicated incidents are combined with dangerous circumstances and time pressure. *Shuttle to Mars* was designed to have multiple levels of increasing complexity, to raise the airline pilots' level of experience to prepare them for critical situations. Moreover, increasing the complexity and difficulty will create engaging gameplay by keeping the player challenged [42, 204].

In the game, each mission (i.e., level) consists of a journey during which a series of events occur. The events in the game mimic reality by offering a variety of circumstances.

To achieve transfer [212] from the zero fidelity simulation [192] of *Shuttle to Mars* to the actual work environment of an airline pilot, parallels need to be established. During the design phase, we discussed both the game and reality with experienced airline pilots, to identify viable parallels. The game events are matched with job tasks, based on (1) the essential competencies, (2) their behavioural indicators, (3) working conditions and (4) characteristics of the tasks. See also Figure 3.5 on p. 44.

We have distinguished parallels in three categories, viz. (1) the work environment, (2) the tasks, and (3) the situations. They are briefly described below. These categories are closely connected. Competencies form the common denominator. Competencies are required to interact with the work environment, to perform the tasks and to react to situations. The tasks are partly driven by input or cues from the work environment, and by the situation at hand.

Work environment. Although the spaceship environment is extremely simplified, the similarities between the spaceship and an aircraft are apparent. Both the spaceship and an aircraft are controlled from the cockpit. The cockpit has a dashboard with gauges and dials to monitor the status of the vehicle. There are signals, prominent as well as discrete, indicating issues with the vehicle. The window allows the pilot or player a view on the environment, albeit airspace or outer space. There are co-workers on board doing their job, but who of the co-workers can be called upon to help, and with whom can the player communicate?

Tasks. The main parallel, with regard to the tasks, is that a pilot or a player must continue to perform his primary task at all times. During a flight or a mission, situations may occur that require action. To control the situation, the pilot or player will need to perform secondary tasks. Circumstances (i.e., working conditions) may increase the difficulty of performing those tasks.

Situations. The game has been designed to provide situations similar to situations which a pilot experiences during a flight. In normal situations, nothing out of the ordinary is happening, and the pilot or player is in control of his vehicle. The game events are designed as equivalents to non-normal situations in an aircraft. In non-normal situations, the pilot or player must act. In most cases, he will be trained for this. In the game, combinations of events are designed to represent critical situations to test and develop the competencies of the player.

The events are designed to be meaningful and to provide authentic learning tasks in which the competencies can be developed [201]. The meaningful events are intended to stimulate transfer [212] of the competencies from the game to the actual work environment. To ascertain relevant parallels, airline instructors were consulted during the design of the meaningful events.

Table 5.3 on p. 115 lists the game events that are matched with job tasks. Each game event comprises one or more game tasks that are connected to the ICAO core competencies (Comp.) and behavioural indicators (BI). The events and tasks are described in the first two columns. The third column shows the number and abbreviation of the connected ICAO competencies, and the number and letter of the relevant BI or BIs. In the fourth column, relevant working conditions (WCo) and task characteristics (TCh) are listed. The fifth column shows the description of an actual job task that matches the game event.

The individual events appeal to specific competencies. When events happen simultaneously, the combination also appeals to WM as interruptions must be managed, and tasks must be prioritised. Moreover, simultaneous events lead to more complex situations requiring a stronger competency of WM and PS&DM.

5.4 Playtesting Shuttle to Mars

Many game designers and researchers stress the importance of playtesting within the game design process [19, 66, 143, 173, 174, 180]. Some even consider it one of the most important activities that should be performed early on and repeatedly [19, 66, 173].

In Subsection 5.4.1, we will take a brief look at the purpose of playtests. Next, we will discuss the method of the playtest (Subsection 5.4.2). In Subsection 5.4.3, we will report on the results of the playtest. Subsequently, we will draw a conclusion in Subsection 5.4.4.

5.4.1 The purpose of playtesting

A playtest serves to determine whether a game produces the experience that the designers intended to reach [19]. It also identifies pacing and balancing problems [49].

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 [19].

Furthermore, for a serious game, playtesting is done to determine whether the target audience will be engaged in the game. Without engagement, the educational objective may not be reached.

To perform a playtest, it is not necessary to have a large number of participants. In usability studies, such as playtests, a sample of five users will identify almost as many problems as a larger group [145].

5.4.2 Shuttle to Mars playtest

In this subsection, we describe (A) the method, (B) the participants, (C) the materials and (D) the set-up and procedure of the playtest.

Table 5.3: Meaningful events matched with job tasks

Game event	Game task	Comp. & BI*	WCo & TCh**	Actual job task
Primary task	Plan journey legs	3. AFPM-A: 3d, 4. AFPM-M: 4e		Plan and program route
System failures	Follow blue bubble line	4. AFPM-M: 4a, 4b, 4f	WCo: distractions TCh: accuracy	Stay on course
	Notice system failure	7. SA: 7a	WCo: distractions TCh: difficulty, shared attention	Notice system failures
	Diagnose and choose solution	6. PS&DM: 6b, 6c, 6g 7. SA: 7f	WCo: time pressure	Diagnose and choose the best solution
	Follow procedure to repair system	1. AP: 1b, 1f	WCo: time pressure	Use checklists to perform procedures
Obstacles	Contact crew to repair system	8. WM: 8d	WCo: time pressure	Communicate with crew, delegate tasks
	Notice and identify objects around spaceship	7. SA: 7c, 7f	WCo: visibility, distractions TCh: shared attention, impact	Notice and identify objects around the aircraft
	Adjust course	4. AFPM-M: 4b, 4e	WCo: visibility, time pressure TCh: difficulty	Adjust course if needed
	Blow up asteroid to free path	6. PS&DM: 7. SA: 7h,	WCo: time pressure TCh: solution multiplicity, accuracy	Resort to extreme measures if needed
Beacon Encounters	Adjust course	4. AFPM-M: 4a, 4b	TCh: need for multitasking	Adjust course to reach destination
	React to encounter (negotiate or fight)	7. SA: 7h	WCo: danger, information availability TCh: solution multiplicity	Balance safety and commercial interests when handling a situation
Orders	Observe passing spaceship and answer crew question	7. SA: 7c	WCo: distractions, time pressure	Pay attention to details in surroundings
	Respond to audio call by inputting correct code	1. AP: 1c 8. WM: 8g	WCo: distractions, time pressure	Pay attention and follow protocol
Dashboard alarm	Notice red light and respond by pushing button	1. AP: 1b, 1d 7. SA: 7a	WCo: distractions, time pressure	Stay alert and follow protocol

* Comp. & BI: Competencies and behavioural indicators (see Appendix C.2).

** TCh & WCo: Task characteristics and Working conditions.

A. Method

During playtesting, a player's experience can be identified using a variety of methods [49, 66]. For the *Shuttle to Mars* playtest, the following four methods were applied.

Questionnaire. A questionnaire was presented before and after the playtest to gather information on the gaming experience, enjoyment and understanding of the game.

Thinking aloud protocol. Each participant was asked to vocalise all his thoughts on what he saw, what he did, and what he was expecting to happen, during the playtest and also when answering the questionnaire.

Observation. The participants were observed in person and on video, to register their responses and facial expressions.

Interviews. During and after the playtest, each participant was interviewed to gather background information on their responses and expectations during the game.

B. Participants

Five male participants played *Shuttle to Mars* during the playtest: four airline pilots and one flight simulator engineer. Recruiting the pilots allowed us to test the game with the intended target audience. Although the flight simulator engineer is not trained as a pilot, he has a similar educational level and an interest in aviation.

C. Materials

The playtest was performed with the Beta 1 version of the *Shuttle to Mars* game. This version was played on iPad. It consisted of four missions, two of which were used during the playtest in addition to the tutorial. In the Beta 1 version, not all features were implemented. After the playtest, the game was developed further to be used in the small-scale study described in Chapter 6.

In all playtest sessions, participants received three assignments in a fixed order.

1. Play part of an extended mission without any events.
2. Play the in-game tutorial.
3. Play a short mission with consecutive events, some simple, others more complex.

A protocol, including interview questions (Appendix C.3) and a questionnaire (Appendix C.4), was used to debrief the participants about their experience with the game during the playtest. The questionnaire had 21 questions that had to be scored on a 5-point scale.

D. Set-up and procedure

The playtest was conducted in a meeting room. The playtest set-up involved one participant, one test supervisor and two observers (see Figure 5.4).

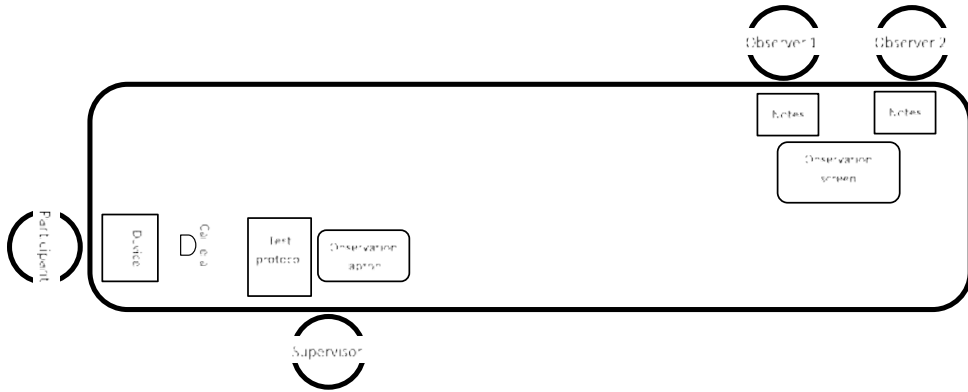


Figure 5.4: Shuttle to Mars playtest set-up

Using mirroring software, the iPad screen was shared on the observation laptop, so that the supervisor could see what the participant did without directly looking at him. The laptop screen was replicated to the observation screen to allow the same for the observers. A webcam was directed at the participant to register facial expressions and responses, and a microphone was used to capture all verbal communications. Recordings were made of the gameplay on the iPad screen, the webcam images and the audio tracks for later analysis.

In the playtests, a protocol (see Table 5.4 and Appendix C.3) was used to assure an identical approach for all participants.

The participants played the Beta 1 version of the *Shuttle to Mars* game on an iPad. They played selected parts of the game and were asked to think aloud during the entire playtest. This allowed us to observe the intended gameplay, and to see whether the gameplay works for players from the target group.

Before starting the playtest and in between assignments, the participants were interviewed, and they filled out a questionnaire.

Table 5.4: Playtest protocol

1. Supervisor	Welcome and short explanation of the purpose of the playtest
2. Questionnaire	First page of questionnaire
3. Supervisor	Short introduction to the game setting
4. Game	Playtest assignment 1
5. Supervisor	Short interview
6. Game	Playtest assignment 2
7. Supervisor	Short interview
8. Game	Playtest assignment 3
9. Questionnaire	Remaining pages of questionnaire
10. Supervisor	Interview on the overall experience and the answers to the questionnaire

During the playtest, the supervisor asked questions about the player's behaviour in the game, when the participant had completed a mission. During the interviews, the observers were allowed to ask questions to complement their notes.

5.4.3 Results

The answers to nine questions in the questionnaire were aggregated into subgroups regarding four important topics: (1) controls, (2) enjoyment, (3) engagement, and (4) parallels with reality. The results (Figure 5.5) 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.

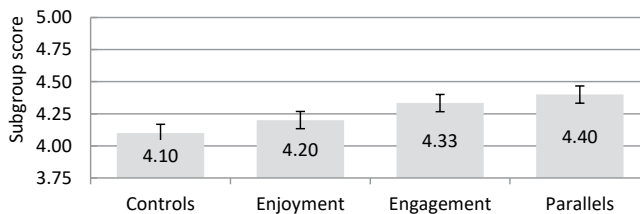


Figure 5.5: Means and SE for playtest questionnaire results

5.4.4 Playtest conclusion

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 has the potential to generate a positive learning effect.

After the playtest, improvements were made to the *Shuttle to Mars* game (see Subsection 5.5.2). The improved version of the game, Beta 2, was used in the study to answer RQ 3 (see Chapter 6).

5.5 Chapter conclusion

In this chapter, we have described the design and development of the *Shuttle to Mars* game. The game design is based on the SG4CD model and addresses the characteristics needed for competency development.

In the design, special attention was paid to meaningful events to provide authentic learning tasks. Subsequently, we have performed a playtest of the game to establish the playability of the game. The outcomes of the playtest were positive and gave confidence for the further development of the game.

Below we conclude on the outcomes of the playtest (Subsection 5.5.1) and provide improvements to the game (Subsection 5.5.2).

5.5.1 Outcomes of the playtest

The playtest showed that the game controls of the *Shuttle to Mars* game were understandable and that the participants enjoyed the game. They were able to distinguish the parallels between the game and aviation reality. Moreover, three of the four participants spontaneously identified the competencies which the game aims to reinforce.

Based on the playtest, we are confident that the *Shuttle to Mars* game will be fun to play and has the potential to generate a positive learning effect.

5.5.2 Improvements to the game

Designing a game is an iterative process. Improvements are made to the game as a result of testing. Within our research, we had only a few iterations available. Although the quality of the game was not a point of evaluation in the playtest (Section 5.4), the participants gave several suggestions for improvement. These and other improvements (see Subsection 6.4.2) should be considered when the development of the *Shuttle to Mars* game is continued.

Suggestions from the playtest participants

The Beta 1 version used in the playtest had only a few missions, which were played partially. Participants played the game on an iPad. Technical issues in the game hampered gameplay. Also, there was some delay in the gameplay due to the software used to record the playtest.

Technical issues. During the playtest, participants played parts of missions to avoid known technical issues. These were resolved to allow the missions to be played completely.

More events. Participants in the playtest indicated that they had wanted to come across more events in the mission. The Beta 1 version was boring at times.

After the playtest, the Beta 1 version was further developed into Beta 2 for the *Shuttle to Mars* study (Chapter 6). Many of the technical issues were solved, and a set of fifteen missions was developed.

