Chapter 2

Background

This chapter provides background information in support of the present research. The problem statement reads as follows.

Problem statement: To what extent can a *serious game* be used to *train airline pilots* to *act adequately* in *critical situations*?

The problem statement contains five main elements: (1) serious game, (2) train, (3) airline pilots, (4) to act adequately, and (5) critical situations. We will discuss these elements to show the relations between them.

For clarity, we will discuss them in a different order than they occur in the problem statement.

First, we look at airline pilots (Section 2.1), followed by how they are trained for their jobs (Section 2.2). Then we will define the critical situations airline pilots may have to deal with (Section 2.3). Acting adequately in such situations requires competencies. Hence, we will look at competencies and competency development next (Section 2.4). Subsequently, we will define game-based learning and discuss serious game design (Section 2.5). Finally, we will tie the elements together in Section 2.6.

The contents of this chapter are based on the following four publications.

1. Kuindersma, E. C., Field, J. & van der Pal, J. (2015). Game-based training for airline pilots. Paper presented at the Simulation-Based Training for the Digital Generation conference at the Royal Aeronautical Society. London, UK.
2. Kuindersma, E. C., van der Pal, J., van den Herik, H. J. & Plaat, A. (2015). Voluntary play in serious games. In A. De Gloria & R. C. Veltkamp (Eds.), *Games and Learning Alliance, 4th international conference* (pp. 131–140). Heidelberg, Germany: Springer.
3. Kuindersma, E. C., van der Pal, J., van den Herik, H. J., & Plaat, A. (2016a). Comparing voluntary and mandatory gameplay. *International Journal of Serious Games*, 3, 17.
4. 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.

2.1 Airline pilots

A little over a century ago, on January 1st, 1914, the first scheduled commercial passenger aircraft flew with one passenger [6]. The flight from St. Petersburg, FL to Tampa, FL is considered to have been the first airline flight, and that makes its pilot, Tony Jannus, the first airline pilot in history. It was ten years after the first controlled, sustained flight of a powered, heavier-than-air aircraft, by the Wright brothers [45].

Definition 2.1 - Airline pilot

An airline pilot is a professional pilot operating a passenger aircraft for a commercial airline.

In this section, we will look at airline pilots. First, we will describe the history of the airline pilot profession (Subsection 2.1.1). Then, we will take a look at the airline pilots of the future (Subsection 2.1.2).

2.1.1 A short history of the airline pilot profession

In the early days of aviation, pilots were pioneers. In the years between the First and Second World War, most pilots flew for the military. When commercial air travel became popular after the Second World War, many pilots joined the airlines after their military careers had ended [120]. For a long time, becoming an airline pilot was a career switch for pilots who had learned to fly elsewhere. The military was the main supplier of the airlines [120].

In 1961, the first integrated, *ab initio* (literally, "from the beginning") education for airline pilots was established, and students without any prior flying experience could register to become an airline pilot [149]. Still, it was not until the 1980s, that becoming an airline pilot shifted from a career switch to a career choice. The *ab initio* training courses delivered increasingly more airline pilots. These pilots were well trained but did not have the experience that the prior generations had gained in the military or other types of aviation jobs [120].

2.1.2 Airline pilots of the future

Currently, there are 290,000 airline pilots in the world, and an increase up to 440,000 is expected in 2027. A total of 255,000 new pilots are needed to accommodate growth and to offset retirement [7].

The pilots of the future, who will be trained over the coming years, are considered to be part of the *Millennial Generation* [136] and the *iGen* [195]. These generations have spent their entire lives surrounded by and using digital technology, making it an integral part of their lives. Prensky [159] called the members of the Millennial generation the "digital natives", contrasting them to older generations of "digital immigrants" who had to learn to adopt digital technologies at a later age.

Members of the younger generations may have specific preferences for learning, work, and communication. They are believed to have different thinking patterns as they are used to receiving information quickly, to multitasking and to parallel processing. They prefer graphics to text, wish non-linear access to information and thrive on immediate satisfaction. This group of learners may benefit from a move away from traditional teaching methods, which generally use lectures to transfer information [40].

Using digital technology would be an appropriate method to educate them. Prensky [159] believes that serious games are better suited for the current generations of "digital natives" than traditional methods, leading to better learning outcomes.

It all implies that other, more appropriate and modern training methods should be used in addition to the traditional methods to utilise the full potential of students from these generations.

2.2 Airline pilot training

In this section, we will look at the development of airline pilot training over time. First, we will describe the early days of aviation, before airline pilot training was standardised (Subsection 2.2.1). Then, we will look at the introduction of standardised licensing and training (Subsection 2.2.2). In Subsection 2.2.3, we will discuss the traditional training approach for the ATPL. In Subsection 2.2.4, we will discuss the modern training approach of the MPL, introduced in 2006. Finally, we will take a brief look at innovations in training delivery in Subsection 2.2.5.

2.2.1 Before standardised airline pilot training

In the early days of aviation, learning to fly carried a certain amount of danger, as it was mostly done by completing exercises in the actual aircraft [150]. The very first pilots learned by discovery, or by observing and imitating experienced pilots. Later on, airline pilot training was formalised and subjected to regulations. The first training devices, or early simulators, were invented around 1910. They allowed a safer way of training [150].

In the early twentieth century, aircraft were mainly used in the military. The First World War required a large number of pilots to be trained. This led to selection criteria and standardised training for military pilots. Although several airlines were established in the period between 1914 and 1922, commercial aviation did not yet catch on with the general public. At that time, air travel could not compete with railroad travel. Since the operating costs of air travel were high and the capacity for passengers was limited, air travel was quite expensive. Moreover, at that time, air travel was not as safe as railroad travel.

In 1918, the US Postal Service started delivering mail by aeroplane as an attempt by the US government to establish an air transportation system. The 1930s and 1940s brought several developments that improved the safety and comfort of air travel, such as the use of radio, and the invention of jet engines, better instruments and the pressurised cabin. Larger and faster aircraft were built, allowing the transport of more passengers [45].

After the Second World War, commercial aviation started to grow, and more airline pilots were needed. They came (again) from the military, bringing along their military training and the experience they had gained [120].

2.2.2 Standardised licensing and training

As air travel was growing, the ICAO was established in 1947, to promote the safe and efficient development of civil aviation. Part of the task of International Civil Aviation Organization (ICAO) was the adoption of standards and recommended practices for international aviation. Among them were the standards for pilot training and licensing, recorded in ICAO Annexes 1 and 6 [39, 207].

The issuance of licences

Since 1947 until today, the requirements for each licence are determined by ICAO in the International Standards on Personnel Licensing [154], but the implementation varies from country to country. Pilot licences are issued by aviation authorities, such as the European Aviation Safety Agency (EASA) in Europe and the FAA in the United States.

The licence requirements are time-based. For each licence, a prescribed number of flight hours is mandatory, as well as a number of theoretical study hours. Different types of flight hours are distinguished, such as Pilot in Command or Instrument Flying hours. Once the required number of hours is logged, the licence will be issued.

In standardised training courses, pilots are trained to meet the requirements of the licence they wish to obtain. Hence, the training of pilots is strongly related to the licensing.

In the traditional training approach, a pilot needs to earn successive licences to obtain an Airline Transport Pilot Licence (ATPL). This is referred to as *stacking*. The pilot first learns how to fly a single-engine aircraft and obtains a Private Pilot Licence (PPL). Then, he learns to fly larger, commercial aircraft and obtains a Commercial Pilot Licence (CPL). Finally, the pilot will earn the ATPL.

The modern approach allows a pilot to obtain the MPL without stacking.

2.2.3 The traditional approach: Airline Transport Pilot Licence

From the introduction in 1947 until now, most airline pilots have been trained in the traditional way. At the end of their training, they have earned the ATPL, which is required to work for most airlines.

Requirements for the ATPL

An ATPL permits the holder to operate as a captain or co-pilot on a multicrew multiengine aircraft, in addition to the single-pilot operation of a single- or multiengine aircraft.

The ATPL requires a total of 750 hours of theoretical study. The pilots need to pass a total of fourteen theoretical exams, on topics such as principles of flight, navigation, and meteorology.

With a CPL and a completed ATPL theory course, a pilot has a *frozen ATPL*. A frozen ATPL allows the pilot to be employed as a co-pilot on a multicrew multiengine aircraft. After meeting the flight time requirements (i.e., 1500 flight hours), the licence will be unfrozen, and a full ATPL will be issued. See Table 2.1 on p. 18 for ATPL requirements.

The general structure of ATPL training

The initial training of airline pilots is generally split into *Ground School* and *Flight School*. After graduation, a pilot will receive additional training from an airline before he may start to work as an airline pilot. Throughout his career, a pilot will need to partake in *recurrent* training to keep his knowledge and skills up to date.

Ground School. In *Ground School*, the extensive theoretical part of the ATPL training is taught, with a focus on knowledge transfer. Ground School usually takes approximately nine months. During this period, students do not get to fly. Traditional training delivery methods such as print media, lectures, discussions, and drill & practice are commonly applied.

Flight School. After successful completion of all theoretical exams, the aspiring pilot will start *Flight School*. This is the practical, flight training part of the ATPL training. A major part of the training is hands-on. It may take place in the actual aircraft or a simulator. Instructors apply observations, step-by-step demonstrations, briefing & debriefing, and in-seat instruction to teach skills and procedural knowledge.

Appendix A describes the training delivery methods commonly used by instructors to teach their students, both in Ground School and Flight School.

After graduation. Once a pilot graduates and finds employment with an airline, he will receive Base Training and Initial Operating Experience training. In Base Training, the pilot will fly the actual aircraft without passengers and with minimal crew, to perform a variety of procedures. For the Initial Operating Experience training, the pilot will be under the supervision of a *line check airman* who is also the captain of the aircraft during his first 40 actual flight hours.

Recurrent training. After obtaining the ATPL, the pilot will need to participate in recurrent training and annual checks. Every airline pilot will take one or more courses each year to keep up his knowledge and skills. These recurrent courses cover a variety of topics including Instrument Rating, Crew Resource Management and Operator Proficiency. Recurrent courses may take place in the actual aircraft or a simulator. The period after which knowledge and skills will need to be updated through recurrent training varies with the subject. It can range from six months to three years.

Adaptations in airline pilot training

Over time, aviation has seen developments that have had an effect on the ATPL training. Aircraft became faster, safer, and highly automated. Incidents involving airliners created new insights into the optimal operation of aircraft. Adaptations were made to the curriculum and the delivery methods to keep the training up to date. However, overall, the training of airline pilots has seen only a few changes since the first adoption of Annex 1 [78, 207].

Simulators. A major innovation in aviation training was the standardisation of simulators as training devices in the 1970s. This allowed part of the training to be moved from the actual aircraft to the simulator, improving safety and lowering costs [150].

Computer-based training. With the advent of the personal computer in education, computer-based training (CBT) also became part of the ATPL courses. In the 1980s, CBT was standardised by ICAO, allowing it as a formal training method for airline pilots to fulfil the requirements in theoretical study hours.

To incorporate these developments, over time the regulations regarding training delivery methods have been modified to allow the use of simulators and CBT.

Multicrew aircraft. Modern airliners are multicrew aircraft. A flight crew generally consists of a *captain* and a *first officer* (also called a *co-pilot*). During a flight one of the two holds direct responsibility for flying the aircraft as the Pilot Flying (PF). The other is referred to as Pilot Monitoring (PM). He carries out support duties and monitors the PF's actions [157]. The PM should be sufficiently aware of the aircraft state in order to assume aircraft control in case of an emergency. A number of fatal aviation incidents have led to new insights into the importance of crew interaction in the cockpit [85].

Automation. The increasing use of highly automated aircraft affects the pilot tasks, roles, and responsibilities in the cockpit and thus changes the competence requirements for future pilots. By the year 2030, necessary pilot competencies are expected to include operational monitoring, visualisation, vigilance, and originality [58]. They need to be able to fully take over from the automated systems at any time, having a clear total picture of relevant elements of air traffic and being able to come up with unusual or clever ideas [58].

New insights and lessons learned from the outcomes of aviation incidents have led to the introduction of new modules into the ATPL curriculum, such as the Advanced Quality Training Program and Upset Prevention and Recovery Training. Multi Crew Cooperation and Crew Resource Management training [85] training have been introduced in order to pay more attention to communication and collaboration.

2.2.4 A modern approach: Multicrew Pilot Licence

In 2006, ICAO introduced the MPL licence, along with the modern educational approach of competency-based training [101, 140, 207, 208]. It was the first major change since the standardisation of CBT in the 1980s.

The objective of the MPL is to provide an alternative pathway for student pilots to become first officers on modern airliners [56, 140, 207]. Right from the start, the MPL training course allows the student pilots to operate as part of a crew in a specific aircraft type for a specific airline [56].

The MPL approach to airline pilot training makes more use of simulators, allowing a reduction in flying hours [56]. There is more focus on multicrew operation and less focus on single-pilot operation.

Competency-based training in aviation

In aviation, competency-based training (see Definition 2.8) is commonly referred to as competency-based education (CBE) and also as evidence-based training (EBT) [61, 101]. We will use CBE to indicate competency-based training throughout this thesis. More recently, the term CBTA has been introduced as the aviation wide approach to competency-based training.

CBE is implemented in aviation for the training of airline pilots, as well as for maintenance engineers, air traffic controllers, and cabin crew. ICAO defines competency as "the combination of knowledge, skills, and attitudes required to perform a task to a prescribed standard under a certain condition" [129, 207]. This corresponds with our definition of competency (see Definition 2.6).

The focus of CBE training programs is on the quality of training rather than on the number of hours. Focusing on pre-specified competencies allows the application of the most efficient means of skill development rather than being obliged to follow a curriculum of prescribed numbers and types of training hours [81, 101]. In general, this makes CBE programs shorter and less expensive than traditional programs. CBE is also considered to be more student-centred, as faster learners are not slowed down by the curriculum, and slower learners can take their time to master a subject without being forced to move on prematurely.

Requirements for the MPL

The MPL permits the holder to operate as co-pilot on a multicrew, multiengine aircraft in commercial air transport with a specific airline. In contrast to the ATPL, the requirements for the MPL are not based on hours but on competency. Still, minimum requirements for flying hours and theoretical study apply. Table 2.1 shows the requirements for both ATPL and MPL. The main differences can be found in the required minimum age and the required minimum total flight hours.

We will discuss competency-based training in more detail in Section 2.4.

The general structure of MPL training

Any MPL training course consists of four phases [78], which are followed by Base Training and Line Training within the airline environment. Currently, the MPL training courses apply the same theoretical examinations as the traditional ATPL training courses. The four MPL phases and their contents are as follows [78].

Table 2.1: ICAO licence requirements for ATPL and MPL

	ATPL	MPL
Purpose	Commercial, professional	Commercial, professional
Minimum age *	21*	18*
Minimum total flight hours*	1500 hours*	250 hours*
Theoretical instruction	750 hours 14 exams	750 hours 14 exams
Flight test	ATPL Skills test	MPL Skills test
Additional ratings	Class/Type Rating	Class/Type Rating
Renewal period	90 days IR: 1 year	90 days IR: 1 year

Differences between ATPL and MPL requirements are marked with *.

1. **Core.** Ground School and basic single-engine single-pilot training
2. **Basic.** Introduction of multicrew operations & instrument flight
3. **Intermediate.** Multicrew operations applied to multiengine turbine aircraft
4. **Advanced.** Type Rating within an airline environment

ICAO, the International Air Transport Association (IATA), and the International Federation of Airline Pilots' Associations (IFALPA) have identified eight competencies to be the ICAO Core competencies [129, 207]. They 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 (see Table 2.2). The ICAO core competencies form the basis of the MPL curriculum. Each competency is divided into a minimum of six and a maximum of thirteen behavioural indicators. The behavioural indicators can be found in Appendix C.1 on p. 211. The behavioural indicators are used to assess the demonstration of competencies by the student pilots. Once the required level of performance is met, the competency is considered achieved [129].

Table 2.2: ICAO core competencies

ICAO Core competencies
1. Application of Procedures (AP)
2. Communication (COM)
3. Aircraft Flight Path Management - Automation (AFPM-A)
4. Aircraft Flight Path Management - Manual (AFPM-M)
5. Leadership & Teamwork (L&T)
6. Problem Solving & Decision Making (PS&DM)
7. Situation Awareness (SA)
8. Workload Management (WM)

Acceptance of the MPL approach

In 2006, the introduction of MPL and MPL training courses was received with scepticism [56]. Advocates of MPL praised the innovative way of training fully capable pilots in less time using technological advancements. In contrast, critics stated that cadets could not gain sufficient practical flying experience due to the reduction in flight time. MPL has advantages as well as disadvantages (see Table 2.3).

Table 2.3: Advantages and disadvantages of MPL [141]

Advantages
▪ Direct training for co-pilot duties. ▪ Training starts in a multicrew environment. ▪ Crew Resource Management and Threat Error Management are core foundations of the MPL syllabus. ▪ Does not dictate a high number of solo flight hours on small aircraft like the current CPL. ▪ Flight academies and airlines must be well-linked and cooperative to develop this new licence. ▪ Airline and aircraft-specific training, therefore, the training is more relevant. ▪ Greater levels of standardisation for pilot training worldwide. ▪ Trainees have their early experiences, and make their initial errors, in a safe and controlled environment.
Disadvantages
▪ Trainees cannot fly solo until sufficient hours are met on single-engine aircraft. ▪ Could be a real threat to safety as it is radically different from the current standard of training. ▪ Actual flying hours are reduced by 50% under the MPL licence compared to CPL. ▪ There are accusations that the MPL licence was driven mainly for economic interests. ▪ Uncertain whether trainees can learn to fly in an environment without real danger to life, e.g., simulators. ▪ Simulators may not be able to replace real-life Air Traffic Control environment.

The discord on the value of MPL reflects on the acceptance. Out of the 91 ICAO member states, 53 had adopted MPL regulations in 2015 [78, 208]. In September 2016, ICAO had registered a total of 1,822 MPL graduates and 3,613 MPL students in 37 MPL programs [75].

2.2.5 Innovations in training delivery

In addition to CBE, several innovations in training and education are promising for aviation training, but are not yet being used on a large scale. Such methods may offer advantages over the traditional training methods, such as (1) flexibility in time and space, and (2) their appeal to the next generation of airline pilots. This thesis focuses on serious games and game-based learning. In Section 2.5, we will elaborate on serious games and GBL.

Below, we define serious games (Definition 2.2) and recall[1] our definition of game-based learning (Definition 1.3).

[1]Please note that we recall a definition that has been defined previously. For this reason, it maintains its original number.

Definition 2.2 - Serious games

Serious games are games - digital and non-digital - with specific learning objectives, that have been designed to balance gameplay (fun) with subject matter (learning) [108].

Definition 1.3 - Game-based learning

Game-based learning is a training concept that uses games with specific learning objectives that have been designed to balance gameplay with subject matter, and with the player's ability to apply the subject matter to the real world.

Other technological innovations that may become valuable to supplement the theoretical and simulation-based training of airline pilots are augmented reality (AR) and virtual reality (VR). At this time, AR and VR are not considered as fully independent training methods, but they can be integrated into a serious game. Below, we define and briefly describe AR (Definition 2.3) and VR (Definition 2.4).

Definition 2.3 - Augmented reality

Augmented reality is a live view of the physical, real-world environment of which elements are augmented in real-time by computer-generated sensory input.

AR is the technology of adding digital information to the physical world. The technology can enhance a user's current perception of reality. Advanced AR technology can help to make the information about the real world surroundings of the user interactive, and can digitally manipulate them [167].

Augmented reality is currently being used on a limited scale in training, predominantly for explanation purposes. When AR reaches maturity, it can function for a broader range of applications. In potential, AR is suitable for electronic on-the-job support and can, therefore, be used for just-in-time, just-enough, just-in-place training and might replace parts of initial training for aviation professionals [142].

Definition 2.4 - Virtual reality

Virtual reality is the computer simulation of physical presence in places in the real world, as well as in imaginary worlds.

VR environments are mostly visual experiences, displayed on a computer screen or through special head-mounted displays. Some simulations include sensory information, such as sound and even tactile information. The technology of creating a virtual world immerses the user.

While wearing a VR headset, the user is mostly unaware of the actual environment. The immersion effect gives the user the feeling they are present in the virtual environment. As a result of this effect, VR may be used in pilot training to replace or complement certain training in flight simulators [202]. This would decrease costs, and it may allow for more personalised and even unsupervised training. The high level of immersion of VR technology can also support specific individual training needs [142].

2.3 Critical situations

In this section, we will first look at the classification of situations into normal and non-normal situations, which is commonly used in aviation (Subsection 2.3.1). Then, we will define critical situations as a specific category of non-normal situations (Subsection 2.3.2).

2.3.1 Normal and non-normal situations

In aviation, situations are commonly categorised as *normal* or *non-normal* situations. *Normal* situations are those in which everything goes according to the plans and procedures. The plans and procedures are recorded in Standard Operating Procedures (SOPs). The SOPs contain standard checklists that should be accurately followed for a wide range of tasks in normal situations. Airline pilots working for any airline will receive the SOPs from their company.

A situation in which it is not possible to operate the aircraft using the normal procedures is considered a *non-normal* situation. SOPs also include many checklists that must be followed in non-normal situations. A non-normal situation is not necessarily an emergency. It may become an emergency when the safety of the aircraft or persons on board or on the ground is endangered [59]. The SOPs also include checklists for many different emergencies. Non-normal situations or emergencies occur every day but rarely result in accidents [25].

In this thesis, we do not focus on all non-normal situations or even on all emergencies. We focus on *critical situations* (see Definition 2.5).

2.3.2 Defining critical situations

During a flight, there may be a moment that something unexpected happens, i.e., what happens does not match with what the pilots anticipated [185]. Most of these unexpected events do not pose a problem, as pilots are trained to handle them by using the checklists and procedures. When an event is unexpected and potentially dangerous, and, on top of that, unknown to the pilot involved, we define it as a *critical situation*.

Definition 2.5 - Critical situation

A critical situation is an event during any stage of flight, that is unexpected and unknown to the pilot involved, and potentially dangerous.

Hence, a critical situation is an unexpected non-normal situation, for which the pilot does not have a checklist or procedure, either because they do not exist or the pilot is unaware of them. A critical situation may (momentarily) surprise the pilot, causing him to lose his grip on the situation, and the situation may become an emergency. In critical situations, the pilot's abilities to stay calm, think, and act are essential. In Chapter 5, we will investigate the competencies needed to act adequately in these situations.

2.4 Competencies

In this section, we will look at competencies and competency development. First, we will define competencies and competency development (Subsection 2.4.1). Then, we will take a look at competency-based training (Subsection 2.4.3) and training design for competency development (Subsection 2.4.2).

2.4.1 Defining competencies and competency development

The word *competency* is closely connected to *competent*. When an aircraft is boarded, one expects the crew to be competent. In everyday usage, this means that they are expected to do their job correctly. According to the Oxford Living Dictionaries [37], we count on them "having the necessary ability, knowledge or skill" to fly that aircraft safely. One may also assume that they will be efficient and capable.

Competencies are more than just skills. Skills indicate *what* an individual needs to be able to do, to perform his job, whereas competencies indicate *how* an individual needs to behave or act in order to be successful in his job. In competencies, the whole is greater than the sum of its parts. The skills are interrelated with knowledge and attitude.

Definition 2.6 - Competency

A competency is an integrated set of knowledge, skills, and attitudes that allows an individual to perform a task or activity within a specific job and under a variety of job circumstances.

Competencies are commonly described in terms of knowledge, skills and attitudes (KSA), and assessed by observing behavioural indicators [177]. The same terms are used in Bloom's taxonomy of educational objectives [10, 21] which is a classification of behaviours that are important in learning. The taxonomy was originally published in 1956 [21] and has been updated since [10, 31]. Bloom's taxonomy distinguishes between three types of learning objectives, viz. (1) cognitive (knowledge), (2) psychomotor (skills), and (3) affective (attitudes). It provides hierarchical models for each of the three learning domains.

Within the domains, learning objectives are classified based on increasing levels of complexity. These levels go from simple to complex, from concrete knowledge to abstract evaluation. Learners should go through all levels to develop knowledge and skills that are internalised and can be used in new situations.

The process of competency development is a series of doing and reflecting, in which a person moves through five levels of competence [53]: (1) novice, (2) advanced beginner, (3) competence, (4) proficiency, and (5) expertise. The objective of professional training is to help the novice student to become proficient at his job, and to become an expert eventually.

In competencies, knowledge, skills and attitudes are integrated. This makes the development of competencies more complex than acquiring knowledge or learning a skill [201]. This complex learning involves the coordination of constituent skills and transfer of what is learned from the learning environment to the work setting [201].

We define competency development as follows.

Definition 2.7 - Competency development

Competency development is the acquisition and enhancement of competencies, either through experience or through training [152].

2.4.2 Training design for competency development

Instruction within a competency-based curriculum is not necessarily designed to support competency development. CBE and its underlying theories are curriculum theories, and not so much an instructional design theory [132]. CBE gives guidelines on how to build a competency-based curriculum, but it does not provide guidelines for the design of the instruction or the form of the training.

Van Merriënboer and Kirschner [201] list nine examples of theoretical design models that can be applied for complex learning. These models converge on one central point: the need for authentic learning tasks as the driving force for complex learning. Authentic learning tasks help learners to integrate all parts of a competency (knowledge, skills and attitudes). They stimulate the coordination of constituent skills, and they facilitate the transfer of what has been learned to new situations and tasks [107].

Among the nine theories mentioned by Van Merriënboer and Kirschner [201] are the well-known cognitive apprenticeship theory [36], the constructivist learning environments [96], and the 4C/ID model [198]. Of these theories, we find in particular the Four Components for Instructional Design (4C/ID) model interesting for our research. Van Merriënboer [198] introduced the 4C/ID model in 1997, providing guidelines for instructional design for competency development. The theoretical model of 4C/ID has later been adapted by Van Merriënboer and Kirschner [201] to provide more concrete guidance in the prescriptive "Ten Steps to Complex Learning" approach.

In Chapter 3, we will use the 4C/ID model as the basis for answering RQ 1. Whereas the other models are mostly focused on curriculum design in general, the 4C/ID model is more specific and provides guidelines to design learning activities. On the design research map Sanders [176], the 4C/ID model can be positioned as a research-led model with an expert mindset. In Section 3.2, we will translate the components of the 4C/ID model into game elements.

2

The 4C/ID model

The 4C/ID model [199] describes training environments for complex learning in four interrelated components: (1) learning tasks, (2) supportive information, (3) procedural information, and (4) part-task practice (see Figure 2.1). We follow the order of the components as given by Van Merriënboer and Kirschner [201]. They describe the four components as follows [201, p. 12-13].

1. ***Learning tasks.*** *Authentic whole-task experiences based on real-life tasks that aim at the integration of knowledge, skills, and attitudes. The whole set of learning tasks exhibits high variability, is organised into simple-to-complex "task-classes", and exhibits diminishing learner support within each task class.*
2. ***Supportive information.*** *Information helpful for learning and performing the problem-solving, reasoning, and decision-making aspects of learning tasks, explaining how a domain is organised, and how problems in that domain are (or should be) approached. Supportive information is specified per task class and is always available to learners. This information provides a bridge between what learners already know and what they need to know to work on the learning tasks successfully.*
3. ***Procedural information.*** *Information prerequisite for learning and performing routine aspects of learning tasks. Procedural information specifies exactly how to perform the routine aspects of the task and is best presented just in time, precisely when learners need it. It is quickly faded as learners gain more expertise.*
4. ***Part-task practice.*** *Practice items provided to learners to help them reach a very high level of automaticity for selected routine aspects of a task. Part-task practice typically provides vast amounts of repetition, but only starts after the routine aspect has been introduced in the context of a whole, meaningful learning task.*

The 4C/ID model offers a holistic approach to designing training environments for the development of competencies. It aims to design training environments that let students acquire and transfer professional competencies to an increasingly varied set of real-world contexts and settings [199, 201]. The model revolves around whole-task practice to integrate knowledge, skills and attitudes, i.e., competencies. A task is not divided into steps that are practised separately and then combined, but it is practised as a whole. This allows the student to perform the task in a way that resembles the task performance in a job setting.

Any learning task should be authentic. The idea of authentic learning tasks is the core of the 4C/ID model. Authentic learning tasks are realistic and meaningful. They challenge the student to apply knowledge and skills within a context similar to the working environment. Learning tasks consist of multiple assignments, in which both repetition and variation are important.

The learning tasks are combined into task classes, based on complexity. Within the task class, learning tasks are varied to improve transfer of the acquired competencies. Learning tasks and task classes are sequenced to allow a gradual increase in complexity. Guidance and support should gradually decrease during a training program.

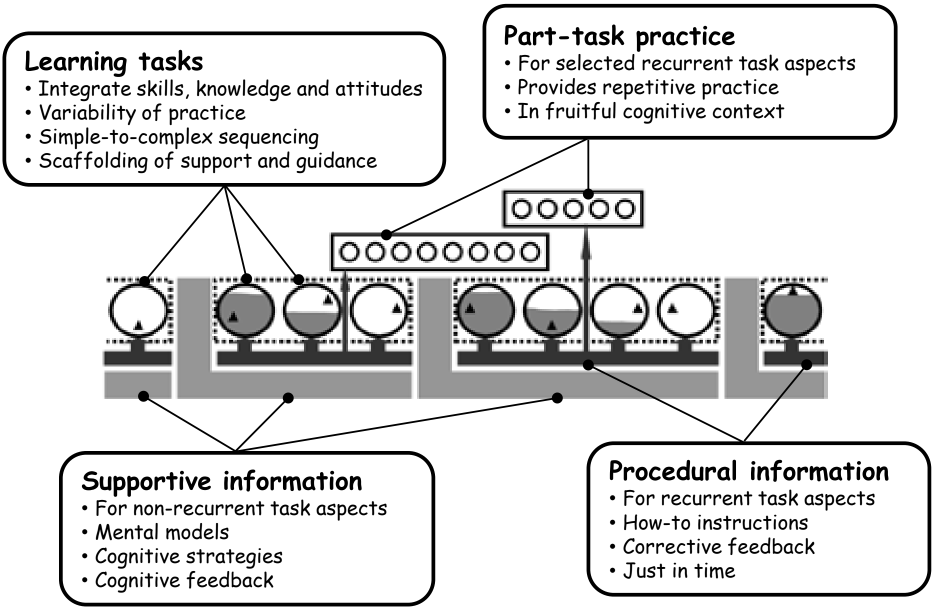

Figure 2.1: Four Components for Instructional Design (4C/ID) [201]

The 4C/ID model links to multimedia principles [200], allowing the model to be used in digital environments, such as serious games. Several studies have applied the 4C/ID model to game design [60, 88, 126, 196]. Although these studies have linked game characteristics to the elements of the 4C/ID model, none of the studies is conclusive about what elements should be present in a serious game to support competency development.

With our research, we aim to provide guidelines about what elements to include in the design of a serious game for competency development. In Section 3.2, we will translate the 4C/ID model into characteristics that should be represented by elements of a serious game for competency development.

2.4.3 Competency-based training

In Subsection 2.2.4, we have briefly discussed competency-based training, which in aviation is commonly referred to as CBE.

Although CBE originated in the 1960s, it has been getting more attention since the turn of the century. CBE is a popular model for curriculum development, flowing from a behavioural foundation. CBE can be a highly effective training approach, particularly when the curriculum is specified and sequenced [132].

We define competency-based training as follows.

Definition 2.8 - Competency-based training

Competency-based training is a student-centred training approach that measures learning outcomes rather than time. Assessment is based on students demonstrating specific behaviour associated with competencies.

The theoretical origins of CBE are not well established. According to McCowan [132], CBE originates from two learning theories, viz. (1) Thorndike's behaviourism and (2) Taylor's scientific management. McCowan [132] also connects CBE to Dewey's progressive education. Hodge [87] speaks of "theoretical resources grounded in behaviourism and systems theory" and of "humanist contributions in the form of mastery learning". Magnusson and Osborne [127] state that CBE includes "elements of programmed instruction, specified behavioural objectives, hierarchical beliefs of knowledge acquisition and social behaviourist assumptions about learning techniques".

CBE begins with a clear specification of the competencies that are to be developed and at what level the students should master them [16]. These specifications are made available in competency texts, which are commonly developed by educators in cooperation with the work field [101]. If a student can show evidence that he already has mastery of a particular competency, he should be allowed to move to the next level. This evidence can be provided through a prior learning assessment, such as a test or a completed project. A student's rate of progress through a programme is based on the mastery of the competencies, instead of time or the number of courses completed [101].

Competency-based training in aviation

In aviation, CBE is also gaining popularity (see also Subsection 2.2.4). Although the adoption of CBE is increasing, the training approach is not free from criticism [101]. After implementing the MPL training in 2006 (see Subsection 2.2.4), ICAO is now (2019) proposing to extend CBE to the training of all commercial pilots as well as other groups of aviation personnel, such as aircraft maintenance personnel, air traffic controllers, and cabin crew [2]. For this purpose, ICAO has installed a CBTA task force and updated the "Procedures for Air Navigation Services - Training" documents (PANS-TRG) [162]. Specifically, Amendment 5 will introduce (1) revised definitions for terms related to competencies, (2) a description of how competency-related concepts are interlinked, and (3) a generic methodology to design competency-based training and assessment. This amendment will become applicable in November 2020.

2.5 Game-based learning

This section will provide a background to the topic of game-based learning. First, in Subsection 2.5.1, we will define game-based learning and the related concepts of gamification and simulation. Then, in Subsection 2.5.2 we will look at serious games research. In Subsection 2.5.3 we will discuss the voluntariness of gaming. Finally, in Subsection 2.5.4 we will look at game-based learning for aviation.

2.5.1 Defining game-based learning and serious games

GBL is also commonly referred to as *serious gaming*, although this term is slowly being replaced. Abt was the first to introduce *serious games* in relation to instruction in 1970 [1]. However, the term was popularised by Sawyer and Rejeski in 2002 [179]. Even before Abt introduced the term, it had already been used in different contexts [51]. The actual use of games for learning is not a recent practice [188, 209]. The essence of serious games is play, which has a vital role in human development. Children acquire many essential competencies and develop important social structures by means of play [89, 155, 204]. This has long been acknowledged in the development of young children, but also applies to adult learning. Games have been used in training for centuries [135, 188, 209]. The use of war games as military exercises has been traced back as far as 4000 years ago [135], and role-playing has been long integrated into training such as for sales and communication skills.

Although the first use of the term *serious gaming* [1] focused on non-digital educational games, nowadays it includes both digital and non-digital games. The current perception emphasises digital, online games, but analogue games, such as board games, are still widely used.

In education and training, games are increasingly accepted as a way to inform and instruct. Several terms are applied to indicate this use, such as game-based learning, educational games, instructional games, applied games, edutainment, and serious gaming. In our research, we will use the term *game-based learning* and *GBL*.

In Chapter 1, we defined GBL and serious games. For readability, we recall[2] our definitions of game-based learning (see Definition 1.3) and serious games (see Definition 2.2) here.

Definition 1.3 - Game-based learning

Game-based learning is a training concept that uses games with specific learning objectives that have been designed to balance gameplay with subject matter, and with the player's ability to apply the subject matter to the real world.

Definition 2.2 - Serious games

Serious games are games - digital and non-digital - with specific learning objectives, that have been designed to balance gameplay (fun) with subject matter (learning) [108].

There is not one single definition of serious games, but there are many [1, 23, 108, 135, 216]. Serious games share many characteristics with other types of games, but in addition, they have a *serious* component. They do not have entertainment as their primary purpose.

[2] Please note that we recall two definitions that have been defined previously. For this reason, they maintain their original numbers.

2

At the basis of most definitions of serious games lies the definition of games in general [1, 89, 97, 133, 174]. Although there is not a particular definition of games that is universally accepted, game designers have reached considerable consensus about the main principles of games [112]. However, a game does not necessarily need to satisfy all principles. Games often have rules, goals, a storyline, and outcomes. They offer interaction, feedback, and competition. Furthermore, and critically important: they are fun, or - as they can be frustrating at times - at least they are *immersive* or *engaging* [112].

We will use the following definition of games.

Definition 2.9 - Games

A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome [174].

Please note that we use the terms *purpose*, *goal*, and (learning) *objective* within the context of GBL. Although these words have a similar meaning, we use them with a specific intent.

The *purpose* of a game is not the same as the *goal* of the game. The *goal* of a game can be to solve a puzzle, rescue a princess or get the highest score, while the *purpose* may be to learn about fractions, a foreign culture or just entertainment. For serious games, the *purpose* is to reach a learning *objective*. In some serious games, the *goal* of the game and the *purpose* of the game (i.e., reaching the learning *objective*) may coincide.

Below, we define these terms.

Definition 2.10 - Purpose

The purpose is the reason for which a game is played or for which it exists.

Definition 2.11 - Goal

The goal is the object of a player's ambition or effort with regard to the game. It is an aim or desired result.

Definition 2.12 - Objective

The (learning) objective is a specific result with regard to learning that a person aims to achieve with available resources and within a time frame. Objectives are specific and easy to measure.

A growing market

Interest in serious games has seen significant growth. A steep increase has been in the number of serious games developed [9, 51] and the value of the global market for products and services related to serious games and GBL [5]. In 2014, worldwide revenues for GBL were $1.8 billion [3]. Since then, interest in GBL has further increased, and the worldwide GBL market is now in a boom phase [5]. In 2017, the market for GBL had reached a value of $3.2 billion [4] and was projected to reach over $17 billion by 2023 [5].

Currently, we see that some economic sectors make more use of serious games than others. The military still has a tradition of using games for training [188, 210] and is a front-runner in the application of GBL. Gaming technology allows the creation of engaging simulations at a lower cost than traditional simulations that are still commonly used in the military [188]. In the past, simulations and games focused mostly on combat training, but more recently, military games are covering soft skills as well.

Besides the military, government, education, health care, and corporations are the primary markets for GBL [135]. Government games are mostly aimed at the training of first responders, e.g., police and firefighters. In education, especially online games are finding their way to the classrooms. These games cover a wide range of topics and are mostly aimed at increasing student motivation. Health care uses games for the treatment, recovery, and rehabilitation of patients, but also increasingly for the training of medical professionals. Corporate training is adopting the use of games in the workplace in addition to e-learning courses.

2.5.2 Serious games research

In addition to the growing number of serious games being developed, there has been an exponential increase in the number of serious games publications [22, 33, 38, 90, 117, 214].

In this section, we will look at meta-analyses of serious games studies, learning in games, and serious games design.

Meta-analyses

Serious games studies are strongly heterogeneous in design, making meta-analysis a difficult task [38].

According to Boyle et al. [22] and Connolly et al. [38], the most reported learning outcome for GBL was knowledge acquisition. Serious games were applied less for skill and social skill acquisition and behaviour change.

Studies show that GBL is beneficial for the development of 21st-century skills and other cognitive skills [137, 166, 183, 194]. Especially strategy games and virtual worlds are found to have the characteristics that support the development of 21st-century skills [166].

Ke [100] reviewed a total of 89 publications on the design, use, and evaluation of computer-based games. The majority of the studies, 65 out of 89, evaluated the effects of a specific game on learning. In many of these studies, the effects of games were compared to the effects of traditional instruction. The second-largest group, 17 out of 89 studies, explored the effective instructional design of games for learning [100]. A common finding in these studies was that learning games need to have features aimed at instructional support.

Research to date has mostly focused on the effectiveness of GBL, and the comparison between serious gaming and traditional training methods (e.g., [146, 153]). Several serious games studies have found evidence of a positive effect of the use of a game on learning. In a meta-analysis, Wouters et al. [213] found a medium effect that confirms that learning may be improved by the use of instructional support in GBL. They observe that instructional support in GBL is desirable when the objective of the game is to help players acquire knowledge and skills. In contrast, Girard et al. [73] claim that there are not sufficient empirical studies investigating the effectiveness of games in learning to conclude that GBL is effective. Although Connolly et al. [38] did find empirical evidence for the positive effects of GBL, they also conclude that more qualitative research is needed to provide more rigorous evidence.

A meta-analysis by Wu et al. [214] has shown that the majority of serious games studies fail to use a foundation in learning theory. The authors also concluded that researchers who do apply a theoretical foundation tend to adopt a more modern learning theory such as constructivism, or modern principles of learning theory, such as experiential learning and situated learning [214].

Learning in games

Learning is inherent in playing games [89, 110, 133, 160, 204]. In a game, a player will start playing and learn in, and from, the process. No player will start by reading the theoretical background of the game. According to this "performance before competence" concept [30], they will experience first, and then relate new information to what is already known. This is an inductive way of learning. Traditional education usually applies a deductive approach.

Players can learn from a game, even if the game is not explicitly designed for learning. Many learning principles can be found in games [70, 71, 72]. Using games for specific learning purposes requires instructional elements and design based on learning theories. Integration of the game design and the instructional design is essential. However, this integration is difficult [108, 171]. Studies show that many serious games are unrelated combinations of subject matter and game elements [171]. Insufficient integration will result in games that are not much fun and not very effective for learning. Learning in games is mostly implicit [165]. The player is not consciously engaged in a learning activity. He is playing the game to reach desired goals, which may lead to a behavioural change [32] or the accomplishment of another learning objective. However, implicit knowledge and skills cannot be consciously manipulated and are not likely to transfer to new situations [165]. Therefore, in serious games, learning will have to be made more explicit in order to allow transfer of skills and knowledge.

Playing a game provides players with a concrete experience of a system [171]. It can be a platform for experiential learning, allowing the player to learn from doing and reflecting [109]. A game is a complete system with complex interactions and relationships, in which skills, ideas, and experiences have a meaning. Learning in such an environment is considered more meaningful than learning without context [70].

A game environment is usually multimodal, using multiple forms to represent information. This supports players in creating more useful mental models [130]. The use of multisensory cues can engage players, direct their attention and provide feedback [52].

Serious game design

Many serious games studies have focused on determining the effectiveness of a game, but there have also been studies that have focused on the design of serious games. Such studies have tried to identify the elements that need to be present in serious games in order for the game to be effective. To illustrate this, we will discuss three studies that can help to design a successful serious game, viz. (1) the RETAIN study by Gunter et al. [80] to design and evaluate serious games with embedded academic content, (2) the LM-GM study by Arnab et al. [11] to map learning and game mechanics, and (3) a study by Paras and Bizzocchi [151] on game, motivation and effective learning.

1. **The RETAIN study.** Gunter et al. [80] proposed a model to support the design of game-based learning, based on specific (educational) needs that are not covered in entertainment games. The principles in the RETAIN are based on three instructional theories, viz. Keller's ARCS model [102], Gagné's learning events [68], and Bloom's taxonomy of learning outcomes [10, 21]. RETAIN is an acronym for the components that a serious game should provide: Relevance, Embedding, Transfer, Adaptation, Immersion, and Naturalisation. Gunter et al. [80] have found that endogenously embedding the content makes sure that the gameplay is relevant as well as immersive.

2. **The LM-GM study.** The Learning Mechanics Game Mechanics mapping model (LM-GM) was introduced by Lim et al. [123] and evaluated by Arnab et al. [11]. The model aims to support the design and analysis of serious games by reflecting on pedagogical and game elements present in a serious game. The authors have extracted learning mechanics and game mechanics from literature. The model links the pre-defined learning elements to the pre-defined game elements. LM-GM-based analysis of a serious game will lead to a game map connecting the learning mechanics to game mechanics. Such a map, based on the LM-GM model, can also be used to design a serious game.

3. **A study on game, motivation and effective learning.** Paras and Bizzocchi [151] recognise the vital role of motivation in game-based learning. They state that "games foster play, which produces a state of flow, which increases motivation, which supports the learning process". In addition, they state that reflection is also essential. However, they find that in a state of flow, players rarely reflect on their learning. The state of flow is interrupted when players have purposeful and critical thoughts. Paras and Bizzocchi [151] suggest that the best way to implement reflection phases in serious games is by making it endogenous to the gameplay.

To the extent of our knowledge, there have not been any studies resulting in clear guidelines on serious games design guidelines for specific learning objectives, such as competency development.

In Chapter 3, we will attempt to provide such guidelines based on the above models.

2.5.3 The voluntariness of gaming

Many game definitions claim that games should be played voluntarily [26, 69, 89, 133, 135]. In Chapter 4, we will study the effect of voluntary gameplay in GBL, to answer RQ 1. The essence of voluntariness of gaming is that a person has the freedom to choose whether or not to play. Below, we define voluntariness.

Definition 2.13 - Voluntariness

Voluntariness is a choice being made out of a person's free will to play a game, as opposed to being made as a result of coercion or duress.

Once a person decides to play, he is bound by the rules of the game. However, the player is free to continue or stop playing. Once the playing of a game is forced, it ceases to be play [26]. The voluntary character of gaming contrasts with traditional training methods, which are usually mandatory in nature. A student may have voluntarily started a particular training or course, but usually, he will not have a choice in the training methods used.

What does this mean for GBL? GBL is sometimes referred to as *serious gaming*. The term *serious gaming* was meant to be an oxymoron to emphasise the opposition between the playfulness of the game and the seriousness of the message [51]. If games are fun by definition, they cannot be serious at the same time [23, 133]. Also, games are non-productive and separate from the real world [89], whereas serious games have specific learning objectives related to life or work skills [69]. In contrast, Huizinga [89] stated that play is a serious activity and that "fun" and "serious" do not necessarily exclude one another.

Thus we have the following paradox: games should be played voluntarily, but serious games are meant to be instructional, and instruction is typically non-voluntary [69]. This paradox may have an effect on player attitude and, with that, the learning outcome of the serious game. Players may have a more positive attitude when they are allowed a form of voluntariness, i.e., the freedom to choose to play a serious game, which may result in a more positive attitude, higher engagement and more time spent in the game [27].

In most serious games studies (e.g., [84, 138]), participants volunteer to play the serious game, whereas participation is mandatory in an average training setting. Here we face the paradox again. When serious games are to be deployed in a training setting, they will be mandatory as well. However, this conflicts with the assumption that games are played voluntarily.

GBL may be expected to have a more voluntary character by offering a student freedom of choice. The student has the freedom to choose whether to play or not to play the game. Psychological studies have shown positive effects of freedom of choice on motivation and participation [26, 27]. Hence, it is plausible that freedom of choice may also have a positive effect on the learning outcomes of a serious game.

Research [15, 18, 44, 67] has shown that offering learners a choice in their assignments empowers them to take control. It is the start of a nice line of reasoning. Being in control provides the learners with ownership of the learning process and motivates them to be engaged. This increases interest and, with that, it increases the time spent on the chosen assignment. The freedom to choose what, when, and how to contribute to the learning process can motivate learners to participate actively and accomplish more. Motivation and active participation have also been identified as having a positive influence on the effectiveness of serious games.

Heeter, Lee, Magerko and Medler [84] conducted a study of mandatory play, which they refer to as *forced*. They found that non-gamers, with little or no experience with digital games, are likely to be at a disadvantage in GBL because obtaining the intended effect of a serious game depends on how well the game is played. The negative affect that non-gamers experience in a game may interfere with learning or with the cognitive benefits. Their study also included *resistant* players who would not play the game if they did not have to. They have less attention for the game they have to play, and they experience less positive and more negative feelings about that game. Heeter et al. [84] concluded that serious games are least effective for players who dislike a game, and most effective for those who like it.

If they do not play a game by choice, players may still consent to play the game. As such, consent is related to freedom of choice. Mollick and Rothbard [138] examined the role of consent as a psychological response to *mandatory fun* in gamification in the work environment. They found that games which employees consented to, significantly increased their positive affect, while resistance resulted in a decrease in positive affect and a marginal decrease in performance. Mollick and Rothbard [138] concluded that employees who play games outside of work are more likely to consent to games in other settings and that individuals who are allowed to choose which game to play show higher levels of consent and *perceived control*, i.e., a sense of control over their own experience. Perceived control is similar to our concept of voluntariness (see Definition 2.13), leading us to expect that playing a serious game voluntarily will increase positive affect and possibly performance.

Based on the motivating aspect of choice (see Subsection 2.5.3) and the original definition of games (see Definition 2.9), we expect that voluntary play, or freedom of choice, will have a positive effect on the outcomes of serious games.

2.5.4 Game-based learning for aviation

Airline pilots receive many hours of training in flight simulators. This allows technical skills to be trained which are needed in situations that rarely occur in real life, or would be too dangerous to train during an actual flight. Serious games could complement pilot training by providing a less complex and less expensive setting for training non-technical skills that do not require a lifelike or high-fidelity environment.

Despite the general acceptance of simulators for aviation training, the aviation sector has not yet embraced GBL. Partly, this is due to a lack of regulation. GBL is not yet allowed as a formal training method for airline pilots. Time spent on serious games cannot be logged as theoretical study hours. New regulations are expected to be installed in 2019.

The other part, we believe, is due to unfamiliarity. Positive effects will need to be proven and supported with scientific evidence to persuade decision-makers. This thesis is part of the research on the viability of GBL for airline pilot training.

In Chapter 4, we will report on a series of experiments measuring the effect of voluntariness on the outcomes of GBL, to answer RQ 2. In Chapter 6, we will report on an experiment measuring airline pilots' acceptance of using a serious game to develop essential competencies for critical situations, to answer RQ 3.

2.6 Chapter conclusion

In this chapter, we have discussed (1) airline pilots, (2) competencies, (3) airline pilot training, (4) critical situations, and (5) game-based learning. Combining the diverse information from the previous sections, we may draw three conclusions about competency development and game-based for airline pilot training that support the problem statement.

Conclusion 1

The first conclusion is based on the following three findings.

1. Critical situations require cognitive skills and competencies that pilots generally develop with experience (see Section 2.3).
2. Most young airline pilots come from an *ab initio* training and do not have the rich experience in aviation that prior generations of pilots had (see Section 2.2).
3. The MPL training course is designed directly around the modern multicrew airline practice, but it provides fewer opportunities to build experience (see Subsection 2.2.4).

Conclusion 1: Since young airline pilots do not have the opportunity to develop through normal experience their competencies that are essential in critical situations, they need to find ways to develop these competencies through training.

Conclusion 2

The second conclusion is based on the following three related findings.

1. The next generation of airline pilots will be *digital natives* [159]. These youngsters have experienced technology around them all their lives, and are believed to prefer the use of innovative, digital technology in learning (see Subsection 2.1.2).
2. The MPL training course is based on modern views of education and will apply modern technology. It allows the training to be tailored to the individual needs of students (see Subsection 2.2.4).
3. Game-based learning is a modern concept in training and education (see Section 2.5).

Conclusion 2: Since game-based learning is an innovative training concept that may appeal to the next generation of airline pilots, that will fit seamlessly within the MPL curriculum, it will be a fitting choice for looking at game-based learning for training the competencies.

Conclusion 3

The third conclusion is based on the following set of three findings, that are again related but different.

1. Part of the airline pilot curriculum (both in ATPL and MPL courses) relates to non-technical skills (see Section 1.1.2).
2. Game-based learning may enable non-technical skills to be trained outside the flight simulators, increasing the time that the flight simulators are available for technical training (see Subsection 2.5.4).
3. Game-based learning has been shown to be beneficial for the development of 21st-century skills. There is an overlap between 21st-century skills and non-technical skills in aviation (see Subsection 2.5.2).

Conclusion 3: Since game-based learning can support the development of skills and competencies outside the flight simulators, it may prove to be a beneficial addition to the airline pilot training curriculum.