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

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Chapter 3

Towards a design model

In our research, we focus on serious games for learning. They can be applied to achieve a variety of learning objectives, such as knowledge acquisition, skill acquisition, and behaviour change [22, 38]. We claim that serious games are also suitable for the development of competencies (see also Subsection 1.2).

In addition to being developed through experience, competencies can be developed by training [152]. For our research, we take as the point of departure that this training can be performed through game-based learning (see Chapter 1).

For this purpose, the serious games will have to be designed in such a way that they support the intended competencies. As far as we know, no models or frameworks have been presented to aid the design of serious games for competency development. In this chapter, we will work towards a design model for serious games for competency development.

It leads to RQ 1, which we will address in this chapter and which reads as follows.

RQ 1: *How should a serious game be designed to support competency development effectively?*

In Section 3.1, we will look at three requirements to develop competencies through game-based learning. In Section 3.2, we will translate the 4C/ID model (see also Subsection 2.4.2) as a starting point for the design of serious games for competency development. In Section 3.3, we will discuss authentic learning tasks as the core of competency development. Subsequently, in Section 3.4, we will identify sixteen essential elements of successful and effective serious games. Then, in Section 3.5, we will introduce the SG4CD model to provide guidelines for the design of serious games for competency development. Finally, in Section 3.6, we will address RQ 1 and give an outlook on further research.

3.1 Three requirements for competency development

The starting point of serious game design should be the learning objective in order to optimise the learning experience. However, to achieve the learning objective, it is pertinent that the game is played. Therefore, the player should be motivated to play the game. Moreover, the learner should be motivated to play the game by its gaming merits, not solely because of its learning objectives. In order to achieve a considerable level of immersion, the player should enjoy playing the game. It means that designing a serious game should mimic the design process of an entertainment game, aiming to make it a successful and enjoyable game. To create a serious game that gets played, it must be designed as an effective entertainment game.

To set the stage for the design of serious games for competency development, we formulate three main requirements.

Requirement 1: The game is playable and attractive.

The learning objective of a serious game is achieved by playing the game. Without any gameplay, the learning objective cannot be reached. Thus, the first requirement for any serious game is that the game is playable (see Definition 3.1) and attractive (see Definition 3.2).

Requirement 2: The game supports learning.

Our research focuses on serious games with a learning objective. Therefore, the gameplay should support the learning intended by the learning objective. The learning objective should be embedded in the core of the gameplay.

Requirement 3: The learning elements address competency development.

Theory on the development of competencies [199, 201] shows that a well-defined set of instructional elements should be present in training materials for competency development. In a serious game for competency development, equivalents of such elements should be implemented.

Definition 3.1 - Playable

A game is considered playable when it is easy to operate, pleasurable to play and it gives the player a positive experience, despite its challenges.

Definition 3.2 - Attractive

A game is considered attractive when its gameplay and visuals are appealing to the player and invite the player back to play again.

To create an effective and successful serious game for competency development, requirement 3 should be the starting point of the design process. In the following sections, we will first identify what is needed for competency development by looking at the 4C/ID model [201]. After that, we will look at what is needed to make the serious game effective and successful.

3.2 Translating 4C/ID into game characteristics

The four defining components of the 4C/ID model are (1) learning tasks, (2) supportive information, (3) procedural information, and (4) part-task practice. These components have been discussed in Subsection 2.4.2. In this section, we will look at what the use of the 4C/ID model [201] means for game design.

When designing a serious game for competency development based on the 4C/ID model, the four components should be taken into consideration in the design. However, from the description of the four components by [201, p. 12-13] (see also Subsection 2.4.2), we infer that the components should be represented in a game by more than four characteristics of the serious game. We have translated the 4C/ID model [199, 201] into six characteristics that should be incorporated in a serious game for competency development (Figure 3.1).

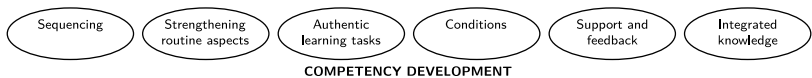


Figure 3.1: Six characteristics that support competency development

Below, we will describe the six characteristics and connect them to the four components of the 4C/ID model (Table 3.1).

1. **Sequencing.** Learning tasks should typically be sequenced from simple to complex. Learning tasks can be divided into task classes. The learning tasks in a class are similar in complexity, but show high variability (e.g., because of varying conditions) and have a gradual decrease in support and guidance. The gradual increase in complexity helps to optimise the learner’s cognitive load.
2. **Strengthening routine aspects.** Certain aspects of a learning task should be performed routinely and automated by a learner. Part-task practice helps learners to automate these aspects. It provides ample repetition and immediate corrective feedback to strengthen automaticity.
3. **Authentic learning tasks.** Learning tasks should be based on complete, real-life tasks that make an appeal on the competency as a unit of knowledge, skills and attitudes. To promote inductive learning and to facilitate transfer, learning tasks should differ from each other in all dimensions on which real-life or professional tasks differ from each other (e.g., different conditions).
4. **Conditions.** All conditions under which a task may be performed should be identified, partitioned into those that affect the complexity of the task and those that do not affect the complexity. The first task class should use the most straight forward conditions, gradually increasing to the most complex in the final task class. The conditions provide variability within a task class.

5. **Support and feedback.** Complete, real-life tasks, even under the easiest conditions, are usually too hard to perform for learners. Support and feedback allow a learner to perform authentic tasks of a particular complexity level (task class) that would otherwise be out of their reach. The support that is given for the learning tasks should decrease during the task class. This is called *scaffolding* [211].
6. **Integrated knowledge.** Any information offered, bot supportive and procedural, should be integrated into the learning task. It should be relevant and offered at the right time during the course. Supportive information can be presented before the learning task through books, lectures or multimedia. It helps with the non-routine parts of learning tasks. New information should be connected to already present knowledge. Procedural information is often presented just-in-time by an instructor, quick-reference guide or mobile app. It is connected with the routine aspects of individual learning tasks. The learner should be able to transform the new information into cognitive rules.

Table 3.1: Connecting 4C/ID components to competency development characteristics

4C/ID Component	Characteristic
1. Learning task	1. Sequencing 2. Authentic learning task 3. Conditions
2. Supportive information	4. Support and feedback 6. Integrated knowledge
3. Procedural information	4. Support and feedback 6. Integrated knowledge
4. Part-task practice	5. Strengthening routine aspects

For a serious game to stimulate the development of competencies, the player should use those competencies to reach the game goal (see Definition 2.11). By offering relevant learning tasks with increasing complexity, the serious game allows the player to apply his competency (see Definition 2.6) under varying conditions. Thus, the game provides the player with useful experiences and allows him to develop the competency. When a player can use an acquired competency in a different situation, this is referred to as *transfer* [212] (Definition 3.3). Transfer is commonly divided into *near transfer* (Definition 3.4) and *far transfer* (Definition 3.5).

For example: learning to tie a shoelace and then tying all kinds of shoelaces is considered near transfer. The situations in which the skill is applied are similar to the situation in which it was learned. Learning about project management in a classroom setting and afterwards successfully managing different projects is far transfer. Projects are different from the classroom, and may also strongly differ from each other.

The intended outcome of the serious game is that the player can apply his developed competency in his work settings. The work situation may resemble the game situations, but in general, the work setting will be different from the serious game environment. Hence this is considered far transfer. The development and transfer of competency are visualised in Figure 3.2.

Definition 3.3 - Transfer

Transfer is the application of what is learned in one task to another task.

Definition 3.4 - Near transfer

Near transfer is the application of what is learned in one task and within one context, to another task that is similar to that of the learning environment within a similar context.

Definition 3.5 - Far transfer

Far transfer is the application of what is learned in one task and within one context, to a different task in a context that is different from the learning environment, e.g., in a real-life environment.

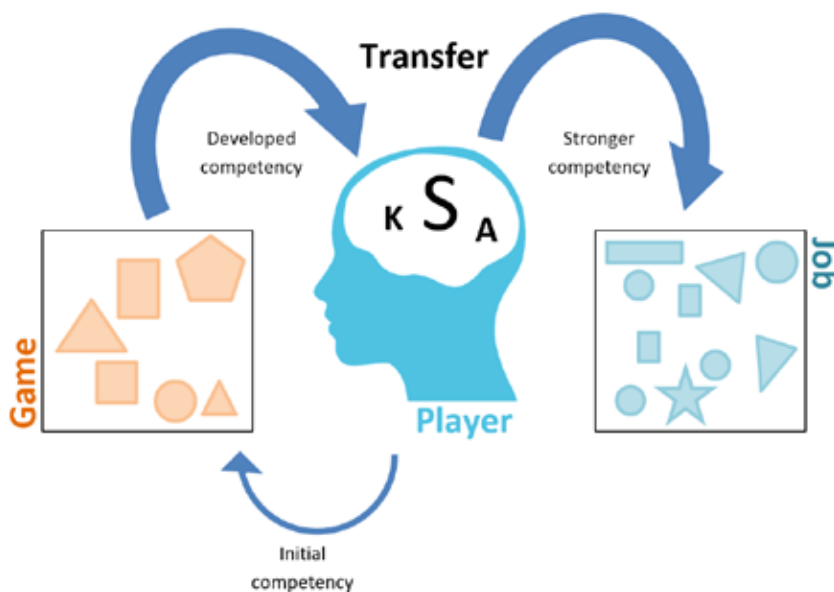


Figure 3.2: Competency development and (far) transfer through a game

The player's initial competency, consisting of KSA, forms the input into the game (left in Figure 3.2). The game provides the player with tasks that are similar to tasks within a job setting (right in Figure 3.2). However, in the game, the tasks are more structured in type and sequence. By playing a series of different types of tasks within the game, the player's competency is developed and strengthened. The player then has a stronger competency that can be transferred to his job setting. Although the tasks within the job setting are usually more varied (i.e., real-time world), the player has been prepared for a wider range of tasks by playing the game.

3.3 Authentic learning tasks

Authentic learning tasks form the core of competency development by training [201]. Competencies do not necessarily need to be trained in a real-life situation, but they should be trained using authentic tasks. With serious games, the authenticity effect may be achieved by using a "zero-fidelity" simulation [192] in which the task elements and contextual elements have close relations with the operational task, but in an abstract way. Zero-fidelity simulations leave out the concrete aspects of a job setting to allow the focus to be on human-centred processes [193]. A serious game for competency development should require the players to demonstrate their mastery of the competency by providing challenging game situations. We refer to such game situations as *meaningful events*.

The starting point for the design of meaningful events is a competency, made up of KSA (see Definition 2.6). A competency is described in behavioural indicators (Definition 3.6). See Appendix C.2 on p. 211 for examples of competencies and behavioural indicators (BI). Figure 3.3 shows the relations between knowledge, skills, and attitude, competency and BI's, viz. BI 1, BI 2, and BI 3.

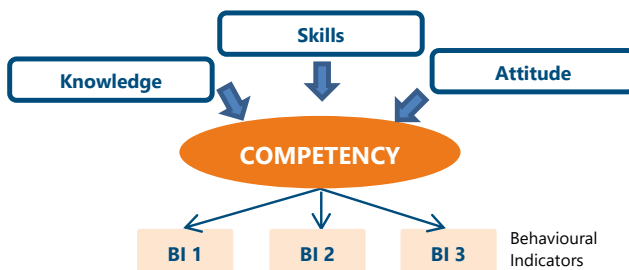


Figure 3.3: Competency and behavioural indicators

Definition 3.6 - Behavioural indicator

A behavioural indicator is a specific description of behaviour that is expected and desired from a person who has acquired a specific competency and is correctly using it [54].

A set of BI's will provide evidence of the extent to which a person has mastered the corresponding competency. The behaviour described in BI's applies to specific job tasks. A task does not necessarily address all behavioural indicators of a competency. In addition to the BI's, there are working conditions (Definition 3.7) and task characteristics (Definition 3.8) that apply to the job task. Figure 3.4 shows the match between the game and the job task, based on working conditions (WCo) and task characteristics (TCh). The match between the game and the job is elaborated upon at the end of the section.

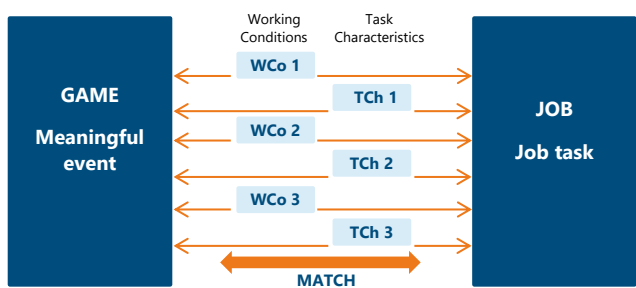


Figure 3.4: Working conditions and task characteristics to match game and job

Definition 3.7 - Working condition

A working condition is a circumstance under which a task has to be performed. Working conditions can be different each time the task is performed. They may affect the complexity of the task and they may add stress to the situation.

Definition 3.8 - Task characteristic

A task characteristic is an attribute that identifies a particular task.

Not all working conditions will always apply to a job task, and a job task does not need to be described with all task characteristics at the same time. In normal situations, time pressure may be low, but in a bad weather situation, time pressure may be extremely high. Both *time pressure* and *weather* are working conditions. A task can be a simple yet important task that needs to be performed accurately. *Complexity* (simple), *importance* and *accuracy* are task characteristics.

Table 3.2 lists eight examples of working conditions and nine examples of task characteristics.

Table 3.2: Examples of working conditions and task characteristics

Working conditions	Task characteristics
Danger/hazards	Complexity
Environmental conditions	Difficulty
Multitasking	Need for interaction
Visibility	Solution multiplicity
Distractions	Accuracy
Information availability	Information flow
Time pressure	Need for multitasking
Weather	Importance
	Task type

To develop the competency, the player needs to perform learning tasks of associated authenticity in the game environment, i.e., they must be associated with the professional's task and its context. This requires the game to contain meaningful events (see also Section 5.3.2) that resemble actual job tasks and that provide challenge.

To create authentic learning tasks, the meaningful game events should match actual job tasks. This match should be based on (1) the competency, (2) the behavioural indicators of the competency, (3) task characteristics, and (4) working conditions. See Figure 3.5 for a visualisation of the relations between competency, job task and game event.



Figure 3.5: Matching meaningful game events with job tasks

3.4 Identifying the elements of serious games

In Section 3.1, we have formulated three requirements. Requirements 1 and 2 are related to two outcomes of a serious game, i.e., to the gameplay and to learning.

In this section, we will identify the elements that serve to make a serious game both a successful game and an effective learning method. We will first present our selection of eleven elements for gameplay (Subsection 3.4.1). Then, we will list our selection of ten elements for learning (Subsection 3.4.2). Please note that both lists of elements are overlapping, resulting in a selection of sixteen elements of serious games.

In total, we have arrived at a selection of sixteen elements of which we claim that they are the basis of creating a successful serious game. Please note that there is no consensus on what constitutes a successful game and there is no fail-safe recipe to create

one. Therefore, our selections are not exhaustive lists, and not all elements need to be present at the same time. In Table 3.3, we will describe all sixteen elements from the perspective of gameplay and learning.

3.4.1 Eleven elements for gameplay

As stated above, there is no standard recipe for a successful game. Even commercial games do not always succeed, despite all the money and effort that is put into the design and development of the game [55, 118]. However, there is some consensus on what constitutes a successful game and the elements that contribute to success [66, 93, 94, 110, 135, 151, 169, 174, 180].

Based on the literature, we have come to a selection of eleven game elements that are commonly present in successful games: (1) Non-linearity, (2) Players, (3) Theme, (4) Levels*, (5) Genre*, (6) Reality*, (7) Narrative*, (8) Rules*, (9) Goals*, (10) Rewards*, and (11) Feedback* (Figure 3.6). The * marks the elements that have a dual purpose (see Subsection 3.4.2). See Table 3.3 for a description of the game elements.

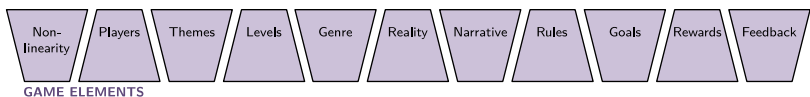


Figure 3.6: Game elements - elements that make the game playable and attractive

3.4.2 Ten elements for learning

Based on the literature on serious game design [11, 128, 131, 135], we have selected ten elements that support learning from inside the game: (1) Levels*, (2) Genre*, (3) Reality*, (4) Narrative*, (5) Rules*, (6) Goals*, (7) Rewards*, (8) Feedback*, (9) Assessment, and (10) Learning content (Figure 3.7). In eight of these elements (marked with *), game design overlaps with serious game design, i.e., these elements have a dual purpose. They serve to make the game playable and attractive, and they also support learning. To create a more specific learning experience, instructional elements can be added to the game that assess the player’s performance or that explicitly provide learning content. These added elements do not contribute to the game experience per se [80].

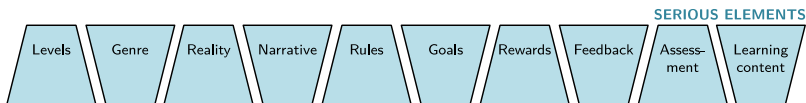


Figure 3.7: Elements *inside* the game that support learning

However, the learning effect does not have to come from the gameplay all by itself. The combination of the game with other training delivery methods in an educational or training setting, so-called blended training, can provide instructional support that will contribute to the learning effect [46]. Serious games can be used in combination with other, more traditional, training methods. Using supportive elements can also make an entertainment game educational. We have selected three elements that support learning from outside the game: (1) Collaboration, (2) Briefing, and (3) Reflection (Figure 3.8). See Table 3.3 for a description of the learning elements.

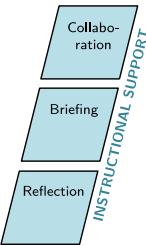


Figure 3.8: Elements *outside* the game that provide instruction support

Table 3.3: Description of serious games elements for gameplay and learning

Elements	Gameplay	Learning
Non-linearity	A linear game is entirely predetermined. The player has no way of influencing the outcomes. Non-linearity provides the player with meaningful choices leading to unique solutions [169]. New possibilities emerge from the player’s actions.	
Players	A game has one or more players who are active participants. They interact with each other or with the game environment to collaborate or compete [144]. The actions of the player(s) make the gameplay.	
Theme	The theme is the setting in which the game is placed, e.g., an ancient civilisation, outer space, or a war zone. Abstract games such as Go and Chess, do not have a theme at all.	

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Table 3.3 continued from previous page

Elements	Gameplay	Learning
Levels*	Most games are divided into levels. Each level has a specific goal or task for the player. Very often, a level must be completed before the player can move on. Subsequent levels have an increasing complexity, and with that, keep offering a new challenge.	Designing different game levels allows for the good design of challenge. For learning, challenge is essential. The level of difficulty of a game should match the capacities of the player. Too difficult causes frustration, too easy causes boredom. For optimal motivation, the level of difficulty should be just above the player's capacities. This is related to the zone of proximal development [204] and Flow theory [42, 43]. For the best gaming experience, the level of challenge should not be constant [180].
Genre*	Games can be categorised into different genres, but there is no consensus on the definition of the genres. Bakkes [14] suggests five genres into which the majority of (video) games can be classified: action games, adventure games, role-playing games, simulation games, and strategy games. Games may combine elements from more than one game genre.	Entertainment games are categorised based on features of gameplay. Serious games use the same genres, but can also be categorised on the cognitive skills and functions they engage [147]. Not every game genre is suitable for every learning objective.
Reality*	Games are commonly described as "separated from real life" [89]. This can be achieved by using fantasy elements, which are also considered to be motivating [69]. However, a game is often an abstraction of reality, and it simulates parts of that reality. The degree of realism of the simulation is referred to as <i>fidelity</i> . Different kinds of fidelity can be distinguished: structural and functional fidelity. Structural fidelity refers to the realism of the physical environment and functional fidelity to the realism of the tasks within the environment. It is possible to maintain a high (functional) fidelity within a fantasy environment.	The amount of realism is not critical. The game can be an abstraction of reality as long as the game has a high functional fidelity. Reality and fantasy go hand in hand. Fantasy is a motivating factor. It can also offer analogies and metaphors for real-world processes, and it may provide a safe environment without real-life consequences [69, 128].
Narrative*	The narrative is the storytelling in a game. It fits in with the theme of the game, and it includes a plot, the characters, and the setting. It also has a specific point of view. The narrative does not interact with the gameplay [110].	The narrative provides a motivating context. For effective learning, the learning content must align with the narrative and the gameplay [52]. There needs to be a meaningful connection.
Rules*	Rules and mechanics go together to let the player experience the gameplay. The rules are directives on how the players should behave. They set boundaries on how the player can interact with the game. Examples: One needs brick and lumber to build a road in <i>The Settlers of Catan</i> game [190]. The dice can be rolled three times in <i>Yahtzee</i> [215].	Rules form the boundaries of the game and set the consequences of violating these boundaries [131]. These consequences affect the player's behaviour and as such the learning outcome.

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Table 3.3 continued from previous page

Elements	Gameplay	Learning
Goals*	A game is won, when the game's goals are reached. The goals are an important motivator. They should be consistent and clear to the players. The goal of the game is generally related to the genre, e.g., it can be to clear the field, beat the opponent, or to reach a destination.	A serious game will have game goals and learning goals (also: learning objectives). They do not need to be the same, but they should both be clear and specific [50]. The level of specificity of the goal in a game can affect the learning outcome [131].
Rewards*	Players can earn rewards via gameplay. A game may give rewards to players, with which they improve their capabilities, capacity or for example, expand their options to customise the game [50]. Rewards motivate players, both intrinsically and extrinsically. Having fun playing the game is an intrinsic reward, whereas receiving a bonus for reaching one's destination is an extrinsic reward.	In behaviourist learning, rewards play an essential role to reinforce learning. A learner will show the intended behaviour to receive the reward.
Feedback*	A game may provide feedback in many ways. Usually, it does so frequently and with intensity [99]. The game will respond to the player's actions. It lets the player know whether these actions are correct, how far he has progressed in the game, or which way he should go.	Feedback is often seen as a motivating element. It informs the player of the progress towards game goals [131]. It is also a reinforcing element in learning, allowing the learner to learn from his mistakes and to prevent him from making the same mistakes again.
Assessment		In-game assessment can provide valuable information about the learning outcomes. Assessment can be done with or without the player knowing it. Game scores may be used to assess the player, but the assessment can also be separate from the core gameplay.
Learning content		The subject matter involved in a serious game can be integrated into the gameplay (endogenous), or it can be added as a separate layer (exogenous) [80, 184]. It is important that offering the learning content does not interrupt the gameplay [95].
Elements outside the game that support learning		
Collaboration		Working with fellow students adds social interaction, shared views, discussion and support. Students can learn from watching each other play. They can deliberate to find the best approach. Playing with or against each other may be a strong motivator.

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Table 3.3 continued from previous page

Elements	Gameplay	Learning
Briefing		Before the game is played, relevant knowledge and skills can be addressed in other training methods, e.g., in a lecture or a book. The teacher can use the briefing as an advance organiser [68] to inform the players about the knowledge and skills they will need in the game and to activate prior knowledge.
Reflection		In between or after gameplay sessions, reflecting on the gameplay experience with a teacher or fellow students can make the implicit learning in the game explicit and transferable to new situations [109].

Elements with a purpose for both gameplay and learning are marked with *.

3.5 SG4CD model: Serious Games for Competency Development

We have translated the 4C/ID model [201] into six characteristics for competency development, and we have identified sixteen elements for serious games. To show the relations between the characteristics and the elements, we introduce the SG4CD model.

The SG4CD model (Figure 3.9) identifies the (serious) game elements and supporting elements needed to accommodate the development of competencies through playing a game. The SG4CD model is a research-led model with an expert mindset [176].

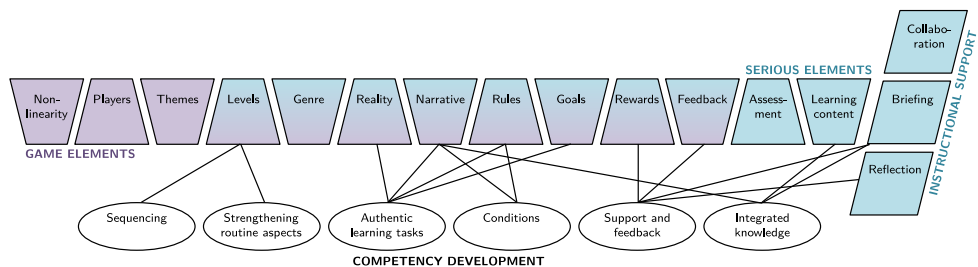


Figure 3.9: The Serious Games for Competency Development model (SG4CD model)

The coloured part of the model represents the serious game itself and the environment in which the serious game is used. The elements derived from game design (see Subsection 3.4.1) are represented in purple. These *game elements* contribute to the game experience. The elements derived from serious game design (see Subsection 3.4.2) are represented in blue. These *learning elements*, inside and outside the game, are responsible for learning. The overlap between game elements and learning elements is visualised by way of the colour gradient.

The characteristics derived from instructional design for competency development (see Section 3.2) are represented in white ovals in the bottom part of the model. These *characteristics for competency development* need to be supported by the serious game and the environment in which it is used. The lines in the model indicate which elements of the serious game can support the characteristics of competency development.

1. **Sequencing.** The game should offer the learning tasks in a sequence from simple to complex. This can be done by organising the game into *levels*.
2. **Strengthening routine aspects.** Routine aspects are automated by repetition. This can be achieved by using a *level* system with recurring tasks.
3. **Authentic learning tasks.** To create authentic learning tasks in a game environment, the game designer must create situations in the game that resemble actual job tasks and that trigger specific competencies. The *narrative* is most important for this, together with the *reality* (or *fantasy*), *rules* and *goals* of the game.
4. **Conditions.** Varying the conditions to provide a variety of authentic tasks throughout the game can be supported by the *narrative* and *rules* of the game.
5. **Support and feedback.** Learning support and feedback can be given through game *feedback* and game *rewards*. *Briefing* and *debriefing* activities outside the game, such as *reflection*, can also provide feedback.
6. **Integrated knowledge.** The knowledge that the learner needs should be provided just-in-time. This is part of the *learning content*. It can be integrated with the *narrative* or offered explicitly inside or outside the game.

3.6 Chapter conclusion

We sincerely believe that serious games can be used for the development of competencies. As far as we know, earlier research did not focus on this application of serious games. Therefore, there is, in our opinion, a need for guidelines on the design of serious games for competency development.

In this section, we will answer RQ 1 (Subsection 3.6.1) and look at further research (Subsection 3.6.2).

3.6.1 Answering research question 1 (RQ 1)

We are now able to answer

RQ 1: *How should a serious game be designed to support competency development effectively?*

First, we looked at what is needed for a successful serious game for competency development. We have formulated three requirements in Subsection 3.1.

1. The game is playable and attractive.
2. The game supports learning.
3. The learning elements address competency development.

From the 4C/ID model [201], we have derived that the development of competencies needs (1) sequencing of tasks, (2) strengthening of routine (part-)tasks, (3) authentic learning tasks, (4) varying conditions, (5) support and feedback, and (6) integrated knowledge. We have shown that these characteristics (see Figure 3.1) can be supported by sixteen elements that are commonly present in (serious) games or that can be added in or around the games.

Based on the literature of game and instructional design, we have identified the elements that are needed for successful serious games for competency development. We have introduced our SG4CD model, which is pictured in Figure 3.9. The SG4CD model identifies the thirteen (serious) game elements and three supporting elements needed (see Table 3.3). With our SG4CD model, we show what game and learning elements should be applied to accommodate the development of competencies through playing a game. Based on our model, serious games for competency development can be designed in a more structured way.

3.6.2 Outlook

Our SG4CD model is a model that is based on literature about game design, serious game design and instructional design for competency development. The model will need to be verified in practice. The design of a selection of games for competency development should be compared to the model to test its validity.

Future research may focus on applying the SG4CD model to other learning objectives. The characteristics for competency development are added in a separate layer in the SG4CD model. Therefore, similar models may be developed for other learning objectives, such as knowledge acquisition or attitude change, by identifying what elements are needed to fulfil the instructional requirements with regard to other learning objectives. The learning elements needed in a serious game to achieve the learning objective can then be identified by combining instructional design for the learning objective with the game and learning elements of our SG4CD model.

