Designing Game-Based Learning for Training Metacognition

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"Het zat even niet in mijn hoofd."

– Amelia, then 5 years old, demonstrating metacognition.

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PROEFSCHRIFT

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Het onderzoek of ontwerp dat in dit proefschrift wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

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chapter one

General Introduction

1. Introduction

1.1 A Case of Metacognition

Below this paragraph, I have listed 16 words. I would like to ask you to set a timer to countdown 1 minute and to use this time to try and memorize all the words listed. When the timer has run out, cover the words with a piece of paper.

ANYTHING	REMEMBER	EVIDENCE	ORGANIZE
CONSIDER	INVOLVED	BUILDING	FOLLOWED
HAPPENED	DECISION	SOUTHERN	SUDDENLY
TOGETHER	POSITION	QUESTION	GROWLING

Let us consider this learning task. Given 1 minute of time, how many words do you think you would be able to reproduce? How sure are you about the correctness of this estimation? These are two questions that involve *metacognition*. Both questions ask you to inspect your cognition to make inferences about learning. The first question asks you to self-evaluate your expected returns of learning or, in other words, to monitor your expected performance. The second question asks about how accurate you expected your estimation to be or, in other words, to monitor your confidence.

Now let us test ourselves. Take a piece of paper and, again, set a timer to countdown 1 minute. Try to reproduce all of the words within this time. When the timer has run out, you can remove the cover and count how many words you have recalled correctly. How accurate was your prediction of your performance? Were you too confident or too cautious? These two questions could provide useful information for learning, because when answered they allow you to adjust your future predictions to be more accurate. This is relevant metacognitive knowledge about yourself as a word-learner.

How did you try to memorize these words? What was your learning strategy? Perhaps you tried to repeat the words over and over, aloud, or silently in your head. Perhaps you grouped the words in groups of four. Perhaps you found conceptual links between the words or created a small story to connect them in a meaningful way. The way you approached this learning task is also useful information because, together with the previous estimations, you can decide whether your approach was effective and whether you would use the same approach for a similar task in the future. This is relevant metacognitive knowledge about how you can learn words.

1.2 A Different Case of Metacognition

Beyond secondary education, learners will only seldom be asked to memorize a list of words. Attention progressively shifts to higher-order learning outcomes that involve making connections between concepts and that favor understanding above reproducing. It should come as no surprise that metacognition is included at the top level of most common taxonomies of learning objectives (Anderson & Krathwohl, 2001; Krathwohl, 2002; Marzano & Kendall, 2007). For example, Bloom's Taxonomy for the cognitive domain defines the dimension of knowledge from the simple to the complex and from the concrete to the abstract, as (i) factual (the basic elements of knowledge), (ii) conceptual (interrelationships among elements), (iii) procedural (the methods of inquiry), and (iv) metacognitive (general knowledge and awareness of cognition) (Anderson & Krathwohl, 2001; Krathwohl, 2002). The prominence of the role of metacognition in learning thus only increases with the complexity of the learning objectives.

Consider Alex [1], a student in higher education who, after three and a half years of studying, was starting out the graduation project to culminate in his bachelor thesis. As his supervisors, we asked for a few paragraphs that summarized his interpretation of a particular part of the relevant theoretical background. For the next meeting, he had compiled a text, indeed, but it consisted mostly of direct quotes from other sources. Subsequent attempts saw the text rearranged, the topic altered, and the form of presentation changed. Unfortunately, however, Alex did not succeed in communicating any of his own theory-informed views.

We inquired about his approach to this part of the graduation. We asked how he had previously approached similar assignments during his study, and we asked

[1] Alex is a pseudonym.

about how he thought about progressing through all the other steps of graduation once we would complete the current step. His answer to all of these questions was as straightforward as it was honest: I don't know. The most prominent problem was not him lacking the conceptual and procedural knowledge to read some of the relevant literature and subsequently summarize and synthesize its contents. The most prominent problem was him lacking the *metacognitive knowledge* and *metacognitive skills* to even detect that there was a problem. He was not so much bothered; studying had taken a few attempts and some effort before, and the current graduation project was no different. The severity of the issue was beyond him.

This account is, by no means, intended to illustrate or emphasize his failure to pick up these competences during his study. Rather, we, as the corps of teachers, had failed him. We had failed to teach him, in the three and a half years prior to graduation, to read and interpret literature in a meaningful way. More importantly, we had failed to confront him at any point with the deficiencies of his approach at a time at which he could have done something about it. But most prominently, we had failed to provide him with the *means to detect* when learning was not producing the expected results, or with the *means to alter* learning in pursuit of those results. In other words, we had failed to encourage and enable Alex to develop the *metacognitive monitoring and regulation* of his learning process.

1.3 A Proposition for Metacognition

In higher education, we want learners to think about their learning, to make judgments about their learning, and to take action when they decide learning could be better. In fact, they must, as higher education cannot be limited to preparing learners for one of the current and specific professions. Instead, we are obliged to help raise critical learners who will continue to question their current competence, seek knowledge and training, and learn long after formal and institutionalized learning has faded from the forefront of their lives (Schön, 1983).

One of the most influential determinants of efficient and effective learning is metacognition: the knowledge a learner has about how they acquire new knowledge and the skills to use that knowledge to monitor and regulate learning (Brown, 1978; Flavell, 1976; Veenman & Spaans, 2005; Veenman, Van Hout-Wolters, & Afflerbach, 2006; Wang, Haertel, & Walberg, 1990). However, not all learners are equally or sufficiently apt in metacognition and, if not attended to, metacognition does not commonly develop autonomously (Veenman, Elshout, & Busato, 1994; Veenman et al., 2006). Therefore, it seems, that providing learners with *metacognitive training* is a very effective way of improving their current and future learning skills and, in turn, their learning performance.

This dissertation concerns a search for instructional interventions that could have made Alex aware of how his learning was proceeding and that could have provided him with the chance to do something about it. This dissertation concerns the design of metacognitive tools that are engaging enough to use, and continue using, while at the same time being effective enough to improve metacognition and, as a result, learning.

2. Context and Challenge

2.1 Context and Problem

The educational context this dissertation is concerned with is *higher education* which, in The Netherlands, is the ensemble of scientific education ("wetenschappelijk onderwijs" or WO) and higher professional education ("hoger beroepsonderwijs" or HBO). Although a gross generalization, the following characterization provides some sense of the present context. WO is primarily focused on academic training (although many study programs focus on a particular professional field, such as law or business), and typically works towards a master's degree (although often after completing an initial phase with a bachelor's degree). HBO is primarily focused on professional training (although many study programs, if not all, involve some form of research training and conducting desk and field research), and typically works towards a bachelor's degree (although often a follow-up master program is available). The curriculum of a study program in higher education is typically divided into three, four, or five years, with the initial years organized as separate courses that are often accompanied by a group project or capstone course, and the later or final years organized around an internship and/or individual graduation work. Education is supported by staff in different roles; it is not uncommon to encounter different teachers for the courses, as well as one or more coaches or tutors for group work, and an academic counsellor or mentor for topics and issues that are not directly related to the contents of the program.

Naturally, many teachers will offer some form of metacognitive support during learning: providing students with reading comprehension strategies, modeling their own thinking and regulation for students to observe, or promoting self-questioning such as through question stems (Hartman, 2001a; King, 1992). At this task- or course-specific and mostly individual level, providing metacognitive support comes somewhat naturally. From the perspective of the student, however, learning transcends the boundaries of courses, periods or blocks, and even years (cf. Derry & Murphy, 1986). Throughout and beyond formal education, being able to recognize a need to learn, to address this need by setting goals, to monitor and control learning activities and learning strategies towards these goals, and to reflect upon both outcomes and process, is essential to succeed.

Unfortunately, the metacognitive knowledge and skills involved in such self-regulated learning are often implicitly expected of students, but seldom explicitly taught within study programs. Moreover, a teacher will not always be available to provide the necessary support when it is needed the most. The problem addressed in this dissertation thus concerns the provision of training and support that aid students in higher education in developing the metacognitive knowledge and skills necessary to study efficiently and effectively.

2.2 Potential for Game-Based Learning

What would such metacognitive training look like? First, an *active* form of training is needed, as learners need not only gain metacognitive knowledge and skills, but also need to practice using these throughout the learning process (Hattie, Biggs, & Purdie, 1996). Second, the development of metacognition takes time and repeated practice, and thus calls upon the motivation of the student to sustain an effort in metacognitive development (Kuhn, 2000; Veenman et al., 2006). This effort is exerted in addition to any effort invested in regular studying. Metacognitive training thus needs to *engage learners* over a longer period of time. Third, a form of training is needed that students can make use of regardless of whether a teacher is available to provide it. In other words, a stand-alone and *self-contained* intervention is desired that learners can turn to, regularly, as they see fit.

Digital Game-Based Learning (GBL) could satisfy these practical needs, while at the same time focusing attention on a novel area of research. First, digital games are interactive in nature and require that players actively make sense of what the objective is, how to achieve it, and how to enact their plans through in-game actions, all while receiving feedback on whether the actions, and the plans, were successful. Thus, when used for learning purposes, digital games can offer an *active* form of training. Second, digital games are known for their motivational qualities: the challenge and fantasy that games can offer is able to captivate a broad range of people for substantial amounts of time. Games have been used to make practicing existing knowledge and skills, as well as acquiring new ones, a more appealing experience. Thus, games can offer the initial attraction as well as the sustained interest to make the learning activities *engaging*. Third, digital games can support a large range of instructional activities, such as direct instruction, practice, feedback, and assessment. Furthermore, digital games can be used almost wherever and whenever a learner so chooses. Smartphones with an internet connection are widely available in higher education in The Netherlands, as are laptops. Thus, digital games can be *self-contained* tools for learning.

Altogether, we consider GBL as a potentially interesting type of intervention for developing metacognitive knowledge and skills in learners. Indeed, various researchers have suggested that metacognition in relation to GBL be further investigated (Hacker, 2017; Ke, 2016; Sitzmann, 2011). As such, we see an opportunity to investigate whether and how GBL can be leveraged for metacognitive training.

2.3 Research and Design Challenge

Some suggestions for addressing metacognition within game-based learning environments (GBLEs) have been put forward from a broader perspective of self-regulated learning (Nietfeld & Shores, 2011) and in specific domains such as STEM-education (Mayer, 2016). However, comprehensively applying these and other suggestions in the design of GBLEs is not straightforward. As GBL attempts to satisfy both learning outcomes and motivational outcomes, the design of any GBLE needs to somehow combine elements of play with elements of learning. Furthermore, the design of a GBLE to address metacognition, specifically, may further complicate matters as the learning outcomes are related to learning itself. As such, the design of such GBLEs is inherently complex.

Furthermore, although ample research on GBL is available, most of this research focuses on training specific knowledge and skills through drill-and-practice. How to leverage the potential of GBL to elicit higher order learning outcomes, such as metacognitive knowledge and skills, is currently unclear. The next step in advancing GBL towards higher-order learning (in general) and metacognition (in specific) is to bring together initial insights, observations, and suggestions, from literature as well as practice, and to comprehensively address the design of GBLEs to include metacognitive learning goals. Investigating how to design GBL for metacognition thus represents both a novel and valuable area of research.

This dissertation discusses the challenge of designing GBLEs to promote metacognition in students in higher education, and the investigations involved in addressing this challenge.

3. Theoretical Background

This dissertation intersects various academic fields and can be considered interdisciplinary in this sense alone. The two key concepts, *metacognition* and *game-based learning*, are both terms with widely varying interpretations and definitions. Considering readership from various backgrounds, we find it necessary and relevant to begin with defining metacognition and GBL in some depth. Subsequently, we will address a third key concept and describe how *metacognitive training* can proceed through instruction, support, and through GBL, and how to assess its effectiveness.

3.1 Metacognition

At the heart of learning is metacognition: a learner's understanding of how knowledge is constructed through learning, and the repertoire of strategies, tactics, and monitoring processes that aid learning (Flavell, 1979). Unfortunately, defining metacognition has been the subject of debate within the field of education. The term itself has been named a superfluous epiphenomenon (see Brown, 1977) and the concept it refers to is notoriously diffuse and prone to inconsistent terminology (Brown, Bransford, Ferrara, & Campione, 1983; Kuhn et al., 1995; Moshman, 2018; Schoenfeld, 1987; Schraw & Moshman, 1995; Veenman et al., 2006). Therefore, an integrative but necessarily limited conceptualization of metacognition that is suitable for our purpose must suffice. For a more comprehensive overview of the history, epistemology, and neurological conceptualizations of metacognition, the reader is referred to Dinsmore, Alexander, & Loughlin (2008), Peña-Ayala & Cárdenas (2015), Van Overschelde (2008), Veenman & Spaans (2005), and Veenman et al. (2006).

In the following discussion we build towards a conceptual model of metacognition as depicted in Figure 1.1. This conceptual model combines a declarative view of metacognition and learning (i.e., defining and relating relevant constructs) with a procedural view (i.e., describing interactions and processes). The declarative elements are intended to help to define the relevant concepts and specify their relationships (cf. Efklides, 2006; Kuhn, 2000; Schraw & Moshman, 1995). The procedural elements are intended to help to conceive how metacognition affects learning in practice. (cf. Efklides, 2011; Nelson & Narens, 1990, 1994; Pintrich, 2000; Shimamura, 2008; Veenman, 2011; Winne & Hadwin, 1998; Zimmerman & Campillo, 2003).

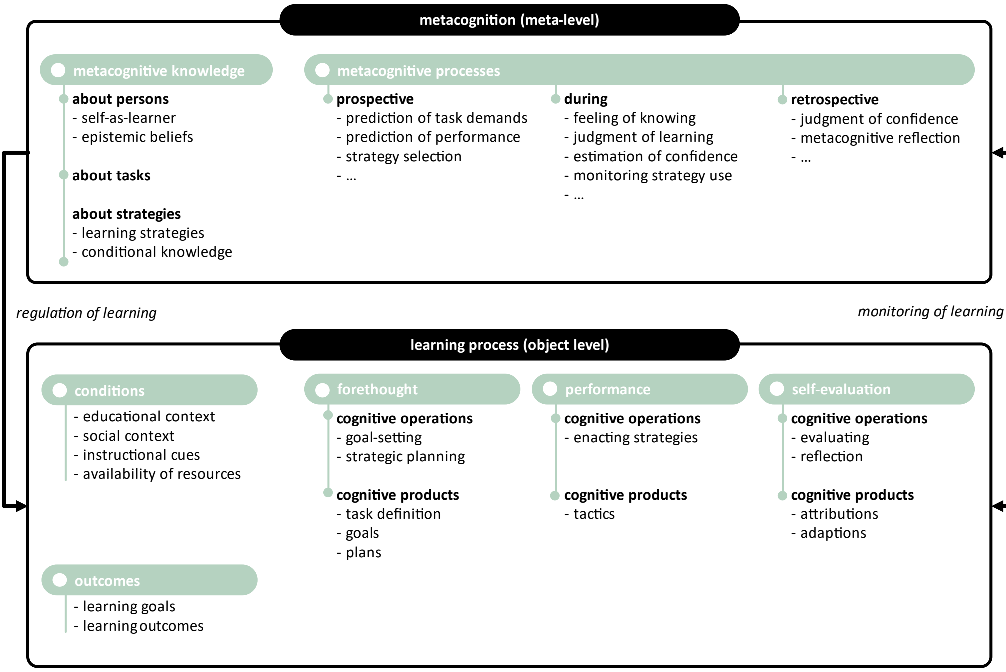


Figure 1.1: A conceptual model of metacognition in learning, based on Nelson and Narens (1990, 1994), Griffin, Wiley, and Salas (2013), Winne & Hadwin (1998, 2013), Zimmerman & Campillo (2003), and Pintrich (2000).

Metacognition and the Self-Regulated Learning Process

How well one understands a particular topic, the likelihood of achieving the learning goals, the expected amount of effort and difficulty involved, the habit to regularly check if learning is going as expected, and the ability to change the course of action are all examples of a large group of metacognitive aspects of learning that affect performance (Kuhn, 2000). Learners who consciously plan, monitor, and evaluate how they are learning are more successful in terms of academic performance and find learning more enjoyable. Such active participants in learning can be viewed as a model to strive for, both as a learner and as a teacher (Ertmer & Newby, 1996; Hartman, 1998; Sternberg, 2001). This type of learning with a high amount of learner agency and crucial role for metacognition is known as *self-regulated learning* (Pintrich, 2002; Zimmerman, 1989; Zimmerman & Campillo, 2003).

We conceive of the learning process as the active, intentional, and directed effort of learners exerted towards achievement of a set of *learning goals* (see Figure 1.1, bottom part). Correspondingly, we define the extent to which learning is effective as *learning performance*: how well a learner is able to demonstrate the learning goals in a test or in a practical situation. The direct *outcomes* of learning are thus the (achievement of the) learning goals and the corresponding learning performance.

Following Winne and Hadwin (1998, 2013), we adopt a cognitive information-processing view of learning in which learners attempt to progress towards their goals by performing *cognitive operations* resulting in *cognitive products*. For example, a learner may enact a strategy (cognitive operation) to arrive at a tactic (cognitive product) for learning. Such cognitive processing takes place in a cycle of *forethought* (i.e., setting goals and making strategic plans for learning), *performance* (i.e., conducting learning activities), and *self-evaluation* (i.e., evaluating and reflecting upon learning) (Pintrich, Wolters, & Baxter, 2000; Zimmerman & Campillo, 2003). The cognitive operations produce *cognitive products* that progress through these phases from task definition, to goals and plans, to studying tactics, to adaptations to cognitive and metacognitive knowledge. However, progression is not strictly linear, as learners may step back and forth between phases and products. In this learning process the learner acts given the *conditions* for learning: The *educational context*, *social context*, and any *instructional cues*, along with *availability of resources* such as time, energy, or support shape how learning will unfold and how effective learning will be.

The prefix "meta" indicates that metacognition concerns that which is about cognition, as Nelson and Narens (1990, 1994) have conceptualized in an object-level and a meta-level. The *object-level* refers to the learning process (Figure 1.1, bottom part) while the *meta-level* represents the metacognitive knowledge about that learning process, and the metacognitive processes affecting it (Figure 1.1, top part).

Metacognitive Knowledge

Schraw and Moshman (1995) categorize *metacognitive knowledge* by its type (i.e., declarative, procedural and conditional) and thereby emphasize that metacognitive knowledge is not different from other knowledge in its form, only in its purpose (Flavell, 1979). However, for our conceptual model, a conceptual categorization of metacognitive knowledge is more appropriate. Flavell (1976, 1979) and others (Jacobs & Paris, 1987; Schraw & Dennison, 1994) distinguish between metacognitive knowledge about persons, about tasks, and about strategies.

Metacognitive *knowledge about persons* foremostly concerns knowledge about *oneself-as-a-learner* (Flavell, 1979; Lin, 2001). Additionally, *epistemic beliefs* about the nature of knowledge and knowledge acquisition play an important role in learning, motivation to learn, and learning performance (Ames & Archer, 1988; Dweck, 1986; Schraw, Horn, Thorndike-Christ, & Bruning, 1995). Together, such beliefs relate to intra-individual and inter-individual differences in learning (Flavell, 1979; Sternberg, 2001), such as knowing you are relatively good at mathematics, but not so much at studying lengthy texts.

Metacognitive *knowledge about tasks* concerns previously accumulated knowledge about cognitive tasks and how to perform them. Combined with an assessment of task conditions – such as availability of time and other resources, the educational context and instructional cues, and the social context – metacognitive task knowledge informs judgments about the cognitive task demands and predictions of confidence and success (Brown, 1978; Flavell, 1979; Winne & Hadwin, 1998, 2013).

Metacognitive *knowledge about strategies*, then, concerns knowledge about what strategies are considered to be effective towards what cognitive goals (Derry, 1989; Flavell, 1979). The difference between a cognitive strategy and a metacognitive strategy is in its use: cognitive strategies are used to make cognitive progress while metacognitive strategies are used to monitor and control it (Flavell, 1979; Klauer, 1988). The same strategy can thus be considered either cognitive or metacognitive depending on its objective. We shall use the term *learning strategy* to refer to such "collections of mental tactics employed to facilitate acquisition of knowledge or skill" (Brown et al., 1983; Derry & Murphy, 1986; Hattie et al., 1996). We consider knowledge of learning strategies, along with the conditional knowledge of when and how to effectively put the strategy to use, as part of metacognitive knowledge (Dansereau, 1978, 1985).

Metacognitive knowledge of persons, tasks, and strategies can, as a whole, be viewed as model of the object-level or, rather, as a *metacognitive theory about learning* held by an individual that informs their conception of learning (Nelson & Narens, 1994; Schraw & Moshman, 1995). Such a theory may be formal or informal, explicit or tacit, based on previous experience or on accumulated beliefs, and may hence be correct or incorrect (Bjork, Dunlosky, & Kornell, 2013; Kuhn et al., 1995; Schoenfeld, 1987; Schraw & Moshman, 1995). Given the conditions for learning, but based on their metacognitive theories, learners set *expectations and standards for learning* and the outcomes thereof. It follows that a particular objective of improving metacognition is to reduce incorrect or unhelpful metacognitive theories and promote correct and supportive ones. Learners can, for example, modify their learning goals and activities based on evaluations of learning (Cnossen, 2009). Metacognitive theories about learning and expectations of learning are two main ways in which metacognition affects the learning process.

Metacognitive Processes

Metacognitive processes mediate between the object-level of learning and meta-level of metacognition through monitoring and controlling cognitive operations involved in learning (Nelson & Narens, 1990; Schraw, 1998). Here, *monitoring of learning* refers to inspecting learning and informing judgments of performance, progress and effectivity while control or *regulation of learning* refers to making informed adjustments in response to such judgments (Flavell, 1979; Griffin, Wiley, & Salas, 2013; Nelson & Narens, 1990, 1994).

Two prominent metacognitive processes that are well-described in literature are *feeling-of-knowing* and *judgment-of-learning* (Brown, 1978). Feeling-of-knowing occurs when a learner becomes aware of having or not having previously encountered and developed some familiarity with the current learning materials (Azevedo, Behnagh, Duffy, Harley, & Trevors, 2012). Judgment-of-learning occurs when a learner becomes aware that they do or do not understand some of the learning materials currently being processed (Azevedo et al., 2012). Both feeling-of-knowing and judgment-of-learning have valence as the outcome can be positive (e.g., feeling that you know the answer) or negative (e.g., judging that you have not learned much). Both are also examples of metacognitive monitoring processes as they involve an inspection of learning. Examples of metacognitive processes of the regulating kind are the selection of a strategy for learning, the allocation of cognitive resources to learning, or the decision to terminate a particular episode of learning.

In reality, metacognitive processes are however more multi-faceted and multi-purposed than the dichotomy of monitoring and regulation processes conveys. Metacognitive processes may often be used *prospectively* (i.e., to predict and plan learning), *during learning* (i.e., to monitor), as well as *retrospectively* (i.e., to evaluate and judge learning) (Brown, 1978; Efklides, 2011; Schraw & Moshman, 1995). Examples that illustrate the diversity of metacognitive processes are the *a priori* assessment of task difficulty and task demands, selection of strategy, and prediction of expected performance, as well as monitoring and regulation of ease of learning, confidence, and strategy use.

Metacognitive processes may occur tacitly in experienced learners, or may occur in response to a cue, or in response to a somewhat spontaneous *metacognitive experience* during the learning process (Flavell, 1979; Griffin et al., 2013). As metacognitive processes can be improved through repeated practice, they are often referred to as metacognitive skills (Baker & Brown, 1984; Brown, 1978; Veenman & Spaans, 2005).

Then, *metacognitive reflection* refers to evaluating the learning process and its outcomes, and updating underlying cognitive assumptions and beliefs, and synthesizing learning (Coulson & Harvey, 2013). In this way, as learners develop their metacognitive abilities, they can apply their metacognitive knowledge and skills in new learning situations, making them more effective learners beyond a single task or a domain-specific learning goal. We therefore consider metacognitive reflection as the metacognitive process that can be regarded as the quintessence of metacognition (Tarricone, 2011).

3.2 Game-Based Learning

Noticing how captivating digital games can be to a wide range of people, and noticing their potential to foster learning, researchers have a longstanding interest in games as motivational and instructional tools (Abt, 1970; Gee, 2004; Malone, 1980; Prensky, 2003), investigating how to "leverage the appeal of play for the purpose of learning" (Plass, Homer, Mayer, & Kinzer, 2019). More than two decades of research and development have since demonstrated that GBL, under the right circumstances, may contribute to motivation as well as learning (Boyle et al., 2016; Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Ke, 2009, 2016; Nadolny et al., 2020; Sitzmann, 2011; Wouters, Van Nimwegen, Van Oostendorp, & Van der Spek, 2013).

Salen and Zimmerman (2004) define a game as "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome", and Plass et al. (2019) extend this definition for GBL as "games with specific learning goals". While definitions of GBL are debated, most scholars agree about the characteristics of games as being rule-based (following clearly defined rules of play), responsive (enabling player actions and providing system feedback), challenging (setting an objective that is achievable, but not straightforward to achieve), and inviting (motivating the player to engage) (Mayer, 2014a, 2016; Plass et al., 2019). The player experiences these characteristics through *gameplay*: the way in which the repeated activities, or sets of activities, are performed throughout the game (Plass, Homer, & Kinzer, 2015). As such, interaction, motivation, and learning should emerge from the system, provided the system is well-designed.

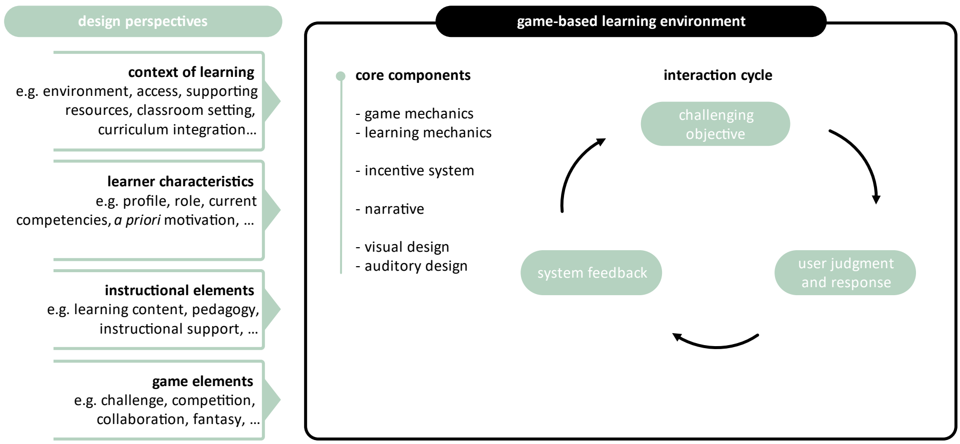


Figure 1.2: A conceptual model of game-based learning, based on Freitas & Jarvis (2009), Garris, Ahlers & Driskell (2002), Plass, Homer, & Kinzer (2015), and Vandercruysse & Elen (2017).

Seeking a definition that emphasizes both the intentional design of such a system and the interaction involved in learning, we define GBL as an approach to learning where gameplay is designed to help learners achieve specific objectives through interaction with the GBLE. The GBLE is the digital and interactive environment facilitating GBL and that may contain game elements and instructional elements (Plass et al., 2015, 2019; Vandercruysse & Elen, 2017). As such, we view a GBLE as a specific type of serious game aimed at learning and as an equivalent to the term educational game. We specifically limit our discussion to digital GBL and digital GBLEs.

In the following discussion we build towards a conceptual model of GBL as depicted in Figure 1.2.

Design Perspectives for Game-Based Learning

Multiple perspectives on playing and learning need to be integrated in the design of GBLEs. For example, the *context of learning* (e.g., environment, supporting resources, classroom structure, curriculum integration) and the *learner* *characteristics* (e.g., profile, role, competencies, performance, *a priori* motivation) need to be considered (Braad, Žavcer, & Sandovar, 2016; Degens, Bril, & Braad, 2015; Van Staalduinen & De Freitas, 2011; Vandercruysse & Elen, 2017). Most prominently, however, *instructional elements* must be combined with *game elements* (Garris, Ahlers, & Driskell, 2002; Ke, 2016; Slussareff, Braad, Wilkinson, & Strååt, 2016; Vandercruysse & Elen, 2017). One of the key challenges for designers of GBLEs is thus to balance learning and play (Ke, Shute, Clark, & Erlebacher, 2019; Plass et al., 2019). If the emphasis is too much on learning, the elements of play will feel superfluous and chore-like, instead of achieving the intended motivational effect. If, on the other hand, the emphasis is too much on playing, the learning content may not come across and no learning effect will be achieved.

One way to combine playing with learning is by alternating playing activities and learning activities, however, such exogenous game design is often not sufficiently engaging to motivate players to continue to play or learn (Rieber, 1996; Squire, 2006). A more integrated way of embedding learning content in gameplay is to employ the narrative qualities of games to foster motivation as well as the construction of a cognitive framework, by designing the setting, characters, and events to foster challenge, fantasy, and curiosity (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Dickey, 2006; Malone, 1981; Rieber, 1996; Van Oostendorp & Wouters, 2017). Another way of combining learning and playing is to align game activities and goals with learning activities and goals, such that engaging with the gameplay becomes equivalent with engaging in learning (Amory, 2007; Arnab et al., 2012, 2015; Bedwell, Pavlas, Heyne, Lazzara, & Salas, 2012; Carvalho et al., 2015; Hung & Van Eck, 2010; Lim et al., 2013). Such an intrinsic integration of learning with gameplay fosters motivation to learn as well as learning, as learning and playing largely coincide (Habgood, 2007; Habgood & Ainsworth, 2011; Ke, 2016).

Core Components of Game-Based Learning

GBL is perhaps best known for its potential quality to combine learning with motivation to learn. Malone (1980, 1981) questioned how the features that make computer games so captivating could be used for learning, striving for games offering "intrinsically motivating instruction". Typical game elements that can foster motivation as well as learning are challenge, fantasy, curiosity, and control from and individual perspective, and competition, collaboration, and recognition from an interpersonal perspective (Amory, 2007; Malone, 1980, 1981; Malone & Lepper, 1987; Sanchez, 2017; Ter Vrugte et al., 2015). For example, the narrative setting and plot in a game may foster curiosity as to what has happened or will happen next, while at the same time using metaphor and analogy to support learning (Barab et al., 2005). Likewise, competition and collaboration may offer social incentives to engage with the gameplay as well as the learning content (Barab, Dodge, Tuzun, Job-Sluder, et al., 2007; Steinkuehler & Tsaasan, 2019; Ter Vrugte et al., 2015). While game designers strive to make the game narrative and mechanics themselves interesting enough to foster motivation (Kenny & Gunter, 2007), games often also employ explicit incentive structures, such as scores, levels, leaderboards, and achievements (Nebel, Schneider, Beege, & Rey, 2017; Plass et al., 2015).

The design of a GBLE typically comprises a number of core components: game mechanics, an incentive system, a narrative, and the visual and auditory design (Plass et al., 2015, 2019). The *game mechanics* define the essential interactions within the GBLE. In view of the goal the player is set to achieve, a game mechanic consists of the actions the game allows a player to take and the corresponding responses the system would provide. The *incentive system* guides the player's behavior in an enjoyable way. Using intrinsic (i.e., that contribute directly to gameplay; e.g., special abilities) and extrinsic rewards (i.e., that do not contribute directly to gameplay; e.g., scores, badges, and trophies). The *narrative* consists of the general setting of the game, and the characters and events contributing to a story. The role of narrative can be strictly motivational, but often also provides a cognitive framework for interpreting and situating the learning content (Asgari & Kaufman, 2004; Malone & Lepper, 1987). The *visual* and *auditory design*, together the aesthetics, determine what the game looks and sounds like. Note that this is a different interpretation of aesthetics than used by Hunicke, LeBlanc, and

Zubek (2004), who use aesthetics to refer to the desired emotional responses as evoked in the player when interacting with the game. Confusingly, as the visual design determines not only how gameplay but also how cues and feedback are displayed, its function is both aesthetic and cognitive (Plass et al., 2015). While there is a lack of research on the role of music and sound in GBL, it is generally agreed that audio can have a substantial effect on a player's emotional state, as well as improve learning through auditory feedback (Pawar, Tam, Plass, & Pawar, 2019).

While most games, if not all, will contain game mechanics and incentives as core components, a narrative is not always present, nor will all games put a strong emphasis on aesthetics. Whichever core components are used, they together allow gameplay to occur and, in turn, foster learning and motivation.

Motivation and Learning from Game-Based Learning

The process of learning through interacting with a GBLE is often described as cycle of user and system actions (Garris et al., 2002; Plass et al., 2015), where (1) the system presents a *challenging objective*; (2) the user makes an interpretation and *judgment* of what is presented and makes a selection of available actions as a *response*; (3) the system provides *feedback* in response to these actions. Note that this loop can be traversed at different speeds: fast-paced (e.g., the game shows a target, the player aims and shoots, and the game awards a score based on accuracy) or slow-paced (e.g., the game presents an incomplete electrical circuit, the player manipulates the circuit to make it work, and the game provides feedback on the solution). Further, note that this loop is a generalization; for example, the system will often provide feedback or change the challenge even when no action is selected.

The challenge provided by the system affects learning directly, as well as through increased engagement, but needs to be in balance with the current skill level of the player (Hamari et al., 2016). Some games employ dynamic difficulty adjustment (Hunicke, 2005) to attempt to achieve and maintain this balance, whereas other games have a built-in difficulty curve that usually increases as the player progresses through the game (Schell, 2019). The feedback provided by the system also affects learning, and needs to take into account the content (e.g., explanatory or corrective, on process or outcome), modality (e.g., auditory, visually, textually), and timing (e.g., immediate, delayed) for the provided feedback to be effective (Johnson, Bailey, & Van Buskirk, 2017). Instructional support, such as reflection prompts or scaffolding through worked examples, can be implemented to further improve learning effectiveness (Wouters & Van Oostendorp, 2013, 2017).

Altogether, the challenges and objectives, actions and responses, and feedback can pertain to gaming, to learning, or when both are designed to fall together, to *intrinsic instruction* (Arnab et al., 2015; Carvalho et al., 2015). Together, the purpose of these elements is to help learners arrive at the *learning outcomes* by fostering motivation as well as learning.

3.3 Training Metacognition

Metacognitive Instruction and Support

Of course, one could teach learners directly about metacognition. For example, one can explain that spaced repetition works more effectively and more efficiently than cramming for a test (Bjork et al., 2013), or one could provide instruction on the declarative and procedural components of planning, monitoring, and evaluation (Zepeda, Richey, Ronevich, & Nokes-Malach, 2015). Such a direct form of *metacognitive instruction* implies that learners must transfer metacognitive learnings to future learning situations, as instruction is separated from application by time (Brown et al., 1983; Osman & Hannafin, 1992). Although early criticism asserted that metacognition must develop over time and cannot be regularly taught or transferred (Gagné, 1980; Klauer, 1988), there is now ample evidence that this transfer can indeed occur and that direct instruction of metacognition is effective and contributes to an altogether awareness of learning (Brown et al., 1983; Hattie et al., 1996; Paris & Winograd, 1990).

However, there is more to metacognitive training. Consider a hypothetical learner who has gained knowledge about all relevant metacognitive strategies and knows when and how to apply them. This learner has successfully reduced a *knowledge deficit* to near zero. It is known from field studies that even a learner with sufficient metacognitive knowledge may still exhibit a *production deficit* and may not produce the behaviors that are expected to align with this knowledge (Veenman, Kerseboom, & Imthorn, 2000; Veenman et al., 2006). In other words, knowing and being aware of metacognition needs to be connected to applying metacognition to ongoing learning in practice. This involves activities such as, but not limited to, getting to know oneself as a learner, knowing how and when to apply which learning strategies, how to monitor learning for effectiveness and efficiency, finding ways to keep track of goals, plans, tactics, evaluations, organizing constructive feedback on both performance (as is common) and approach (not as common), modeling others' behaviors, trying out strategies and evaluating them for effectiveness (Hacker, 2017; Lin, 2001).

It is clear that these metacognitive activities are closely related to and embedded in the learning process itself. In addition to metacognitive instruction, training should thus also involve supportive elements that connect knowledge of learning to applying this knowledge to learning (Bannert & Mengelkamp, 2013; Veenman & Spaans, 2005; Veenman et al., 2006). When learners have access to help while learning, any transfer is reduced as such *metacognitive support* is available during the learning activity. Examples of metacognitive support are processing scaffolds (e.g., providing the steps to be taken), question prompts (e.g., asking about why an answer is thought to be correct), and cueing prompts (e.g., reminding to check on learning progress).

We collectively refer to instructional and supportive mechanisms to promote metacognition in learners as *metacognitive training*.

Metacognitive Training through Game-Based Learning

As we have already mentioned, we find that potentially GBL offers an appropriate method for developing metacognition in learners (cf. White & Frederiksen, 2005, 1998). GBLEs present an active form of learning with a high degree of agency for learners, while at the same time offering the engagement for learners to use and keep using the environment. As such, they might constitute an effective way of training metacognition over the longer period of time that is required (Hacker, 2017; Mayer, 2016). The core question is how we can design a GBLE such that learners are motivated to invest some of their learning effort into metacognition and such that metacognition and ultimately learning are improved.

Previous work on metacognition and GBL has focused on helping learners succeed in learning effectively and efficiently within GBLEs. For example, not all learners may have adequate learning skills to extract the domain-specific knowledge and skills embedded within such complex learning environments, and the high cognitive load required to interact with the game may leave no room for goal-directed behavior in terms of what is relevant for learning (Azevedo et al., 2012; Azevedo & Hadwin, 2005). These obstacles for learning may be alleviated through the implementation of metacognitive support to make the GBL process itself more effective (Azevedo et al., 2012; Wouters & Van Oostendorp, 2017). Potentially, some of the metacognitive outcomes of such an approach could transfer to other learning situations (GBL or non-GBL), however, this is not the primary purpose (Azevedo, 2005a, 2005b).

In our work, the transfer of metacognition from GBL to other learning situations is intentional (Hacker, 2017). In terms of the conceptual model of metacognition (see Figure 1.1) and the conceptual model of GBL (see Figure 1.2), we seek to make inferences about what mechanisms to introduce in the latter that positively affect the former. Or, put in different words, our aim is to improve learning by *improving metacognition*, with GBL as the means to that end, and with a focus on *how to design GBLEs* with that purpose in mind.

Metacognitive Training Effectiveness

Various meta-analyses of instructional interventions provide evidence that training metacognition and self-regulated learning is effective for increasing assessment performance of learners (Dignath & Büttner, 2008; Hattie, 2009; Hattie et al., 1996; Muijs et al., 2014). When we seek to improve metacognition through GBL, we need to determine how to assess the effectiveness of metacognitive training though GBL. While measurement of metacognition is a complex challenge (Oguz & Sahin, 2011; Veenman et al., 2006), we provide a brief introduction here. Specific measures are discussed in the methods section of the corresponding studies.

Three main areas are usually considered when measuring metacognition: (1) the extent to which learners have participated in training (e.g., how much time did a learner make use of the provided intervention, in what ways was the intervention used, what type of interactions occurred); (2) the extent to which metacognitive knowledge and metacognitive processes are present in and used by learners (e.g., what do learners know about their own learning, which behaviors do they produce, what strategies do they use); and (3) the learning performance delivered by learners (e.g., how many test items were answered correctly, what grades do learners achieve, to what extent where the learning outcomes achieved). Research on interventions regarding metacognition tends to focus only on product measures (i.e., effects on academic performance as per the relationship between (1) and (3)) or only on process measures (i.e., effects on metacognition as per the relationship between (1) and (2)) (Muijs et al., 2014; Veenman et al., 2006; Wang, 2015).

Product measures of metacognition attempt to relate direct measures of metacognition to observed performance of learners. For example, researchers may ask learners to make a prospective judgement of performance like we asked at the start of this chapter regarding the number of words you expected to be able to recall. Likewise, retrospective judgements could be collected in terms of predicting how many words were correctly recalled. Contrasting such judgements with observed performance produces measures of calibration: the accuracy of a learners' perception of their own performance (Hacker & Bol, 2019; Pieschl, 2009). As such, absolute accuracy (i.e., the degree to which judgements correspond to performance) or relative accuracy (i.e., the degree to which judgements discriminate between correct and incorrect answers) can be viewed as a measure of metacognition (Rhodes, 2019; Schraw, 2009). *Process measures* focus on whether and how metacognitive training affects metacognition. For example, researchers may ask learners about which learning strategies they know about and which ones they used on a particular learning task (Winne & Jamieson-Noel, 2002).

As different types of assessment are appropriate for measuring different aspects of metacognition, it is advisable to combine multiple assessments (Oguz & Sahin, 2011; Wang, 2015; Zepeda et al., 2015). Key distinctions in measuring metacognition are whether metacognition is assessed online or offline (i.e., measurements obtained during or either before or after task performance) (Veenman et al., 2006) and whether observations or self-assessment is used (Gascoine, Higgins, & Wall, 2016).

Examples of observation-based measurements are the use of thinking-aloud protocols (Ohtani & Hisasaka, 2018), systematic observations (Veenman & Spaans, 2005), computer log data (Snow, 2015; Winne & Hadwin, 2013), and eye-tracking (Taub et al., 2016). Examples of using participants own (re)telling include interviews or open-ended questions (Jacobs & Paris, 1987) and self-report questionnaires (Meijer et al., 2013; Pintrich, Smith, Garcia, & McKeachie, 1993; Schraw & Dennison, 1994). Drawbacks of such self-report measures are that participants may rationalize their answers or even answer with socially more acceptable answers, leading to concerns about validity (cf. Veenman, 2011a). Benefits, however, are that larger groups of learners can be studied without intervening strongly in their learning process or learning environment.

The research in this dissertation, focusing on how metacognition can be trained in real world educational settings, is suitable for using mixed methods to assess metacognition. In particular, GBLEs are suitable for collecting trace data of learner behavior and the educational context makes it possible to employ questionnaires and interviews. As such, we can collect insights on how our designs affect and are experienced by learners, and whether they are potentially effective.

The following chapter outlines the research methodology that we will use to address this aim and discusses the research design. The outline for this dissertation is presented at the end of the next chapter.

chapter two

Research Methodology and Research Design

1. Introduction

In this chapter, we will introduce a research methodology that provides the vocabulary to communicate the relevant design and research processes, their outcomes, and the relationships between processes and outcomes in more detail. We employ this methodology in describing the research design used for this dissertation and we conclude this chapter with a presentation of the flow of research throughout the chapters. However, we begin by identifying the requirements for a research methodology stemming from the aims as outlined in the previous chapter.

It is clear that in this dissertation we will need to take into account current insights on metacognition and GBL. One type of activity will thus be to consult the academic literature to construct some structured overview of relevant state-of-the-art knowledge. It is also clear that this dissertation will involve digital tools that students use during learning. One type of activity will thus be to conceptualize and create such tools based on the available information. We would further like to know if the tools we create do what we expect them to do when they are used by real students in real-world learning situations. One type of activity will thus be to evaluate what happens when these tools are being used. Together, these different types of activities should contribute to a better understanding of the design of GBLEs that promote metacognition in learners.

With the research in this dissertation, we strive for a *practical contribution* for education (i.e., for teachers and learners), as well as for a *knowledge contribution* to advance research in GBL and design of metacognitive training (i.e., for designers and researchers).

The practical contribution is mainly to aid students in higher education to improve the effectiveness, efficiency, and enjoyability of their learning process by improving their metacognitive knowledge and skills. This involves the study of such GBLEs within their target contexts (i.e., examining how students use such a system while learning) and necessitates the collection of different types of data as part of such studies (e.g., investigating effects as well as perceptions).

The knowledge contribution is mainly to inform designers and researchers with insights about how the design of such GBLEs affects learners. This has at least two implications. First, we must acknowledge that the design of game-based metacognitive training transcends a multitude of disciplines, each of which has their own specialized knowledge, terminology, and methodologies. As a non-exhaustive illustration, at the very least we will need to draw from knowledge of instructional design, educational psychology, and pedagogy, as well as from knowledge of interaction design, game design, and educational technology. We will need to identify and define concepts across these and other areas of research and form an integrated understanding that can inform our design and research process. In other words, we will need to work in an *interdisciplinary* way. Second, we will need to navigate the space between the specific implementations we can build and test, and the underlying design assumptions and design knowledge that we want to make inferences about. As we would like to inform designers and researchers with meaningful advice about the design of digital GBLEs that provide metacognitive training, we are seeking insights that could potentially be applied across different learning tools and contexts. In other words, we would like to make a *generalization* step of inferring, from our findings for specific designs, conclusions that can aid future designs beyond what is known for our specific instantiation. In other words, we want our insights to be reusable to some extent.

In this work, we aim to investigate solutions within an educational context. We are not merely seeking to advance insights in GBL, we also aim to contribute concretely to improving learning by designing, implementing, and evaluating real-world GBLEs within real-world educational programs with real-world students. This has two consequences. First, evaluation of proposed solutions typically takes place in practice, i.e., in *real-world educational settings* as opposed to in laboratories. Consequentially, the study of educational interventions often involves a trade-off between representativeness (of the target environment) and isolation of confounding factors (quasi-experiment versus experiment). Most of all, we need to take into account that we want any outcome – both in knowledge and in practice – to be able to migrate from our specific situation and apply to other similar educational settings (Brown, 1992). Second, the design and development of proposed solutions typically takes multiple iterations. Consequentially, the study of educational interventions often involves the creation and evaluation of half-solutions, prototypes, and intermediate steps, of which the lessons learned are translated to further shaping of the solution (McKenney & Reeves, 2012). The research in this dissertation is aimed at investigating the rationale underlying our designs (e.g., models, principles, guidelines). If we want to examine how learners are affected by our designs, we will need to realize the design in the form of a specific educational intervention (e.g., prototypes, products, artefacts) and study that intervention through evaluation. Therefore, we need structured ways of linking the generic models and principles that informed our design to the concrete artefacts that we evaluate. Furthermore, this emphasizes the need to not only seek to assess *whether* a particular intervention is effective, but rather seek to also, and predominantly, identify *why and how* it is or is not effective. In other words, we need to be able to design, develop, and evaluate our solutions in an iterative way.

In summary, we will thus need a research methodology that (1) provides synergy between knowledge contributions and practical contributions, (2) accommodates an interdisciplinary integration of concepts and methods, (3) provides ways of generalizing findings beyond a specific instantiation, (4) supports the study of solutions and half-solutions in real-world practice settings, and (5) supports the iterative design and improvement of such solutions.

2. Design Research

We propose that *design research* provides a methodology that addresses these needs. Design research is the systematic study of designed interventions (Hevner, March, Park, & Ram, 2004; Johannesson & Perjons, 2014; Sandoval & Bell, 2004) and is oriented to finding effects as well as functions – "*understanding how desired and undesired effects arise through interactions in a designed environment*" (Sandoval, 2014). Typically, design research is driven by a desire to address practical issues, is solution-oriented, strives for reusability, and validates solutions based on desirability and effectiveness (Andriessen & Van Turnhout, 2023). As such, design research seems to meet our requirements for a methodology.

Design research combines the aims of design with the aims of science. The primary aim of design is to create *utility*, for example when building a bridge known to withstand the expected loads and safely get people and cargo across. The primary aim of scientific research is to find *truth*, for example in explaining natural phenomena through laws of physics. The aim of design research then, it follows, is twofold: it has a *practical goal* ("utility", as in effective artefacts) to solve complex real-world problems, as well as a *theoretical goal* ("truth", as in justified theory) to generate sharable design theories (De Villiers & Harpur, 2013; Hevner et al., 2004). This aim follows from the notion that research can, in addition to stemming from theory, stem from use (Stokes, 1997) and that the advancement of understanding can be synergetic to the creation of practical applications (Schön, 1983). Design research aims to create interventions that are useful in practice as well as contribute to academic knowledge (Easterday, Rees Lewis, & Gerber, 2018; Hevner et al., 2004; Schoenfeld, 2009).

Different nomenclature is used to describe similar research approaches that combine design and research, typically associated with specific fields, such as *design science research*, stemming from the design of information systems (Hevner & Chatterjee, 2010; Hevner et al., 2004), or *design-based research*, stemming from the design of educational interventions (De Villiers & Harpur, 2013; McKenney & Reeves, 2012).

Frayling (1994) distinguishes between *research into design* (i.e., investigating how designers design), *research for design* (i.e., investigating that what is relevant for the design), and *research through design* (i.e., investigating by means of designing). Research through design, also named constructive design research, aims to uncover reusable design knowledge through iteratively evaluating research-informed designs (Zimmerman & Forlizzi, 2014; Zimmerman et al., 2007). While research through design perhaps lies closest to our aim of contributing to practical solutions as well as to knowledge, design research generally uses methods from other research traditions. For example, conducting a literature review to collect current design insights or conducting an experiment to study working mechanisms can be considered forms of research for design, while at the same time representing traditional research methods.

To avoid confusion, and to focus on the utility and insights we need from a methodology rather than its nomenclature, we will use the term *design research* to refer to the set of cycles, phases, questions, methods, and outcomes as outlined in the following sections. Our purpose here is practical in nature: to facilitate the description of the processes and outcomes they produce as discussed throughout this dissertation.

2.1 Cycles

Hevner et al. (2007; 2004) describe the dynamic relationship between practical utility and theoretical validity using three cycles: a relevance cycle, a rigor cycle, and a design cycle (see Figure 2.1).

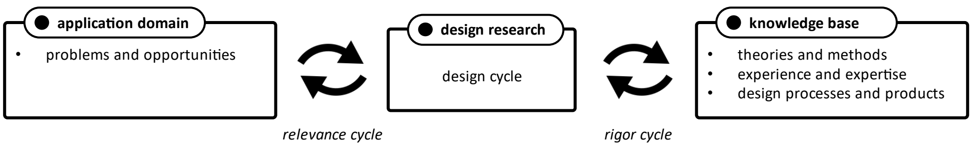


Figure 2.1: A three-cycle view of design research (Hevner et al., 2007; 2004).

The *relevance cycle* is concerned with finding problems or opportunities that have practical relevance in a particular environment and conducting field tests to find out to what extent proposed solutions contribute to solving these problems. The *rigor cycle* is concerned with grounding solutions in current scientific and practical knowledge from the knowledge base and contributing new theories and methods, as well as design processes and products, to that knowledge base. The relevance and rigor cycles thus ensure that solutions are not designed in isolation but are instead informed by current knowledge and relevant to practice. These two cycles also recognize that solutions may be informed and shaped by practice and that their underlying assumptions, their effects, and the methods used to conceive them, may inform future solutions and, hence, represent relevant and possibly new knowledge.

As such, it combines such practical relevance (e.g., requirements from the application domain, field testing of interventions) with academic rigor (e.g., theories, concepts, and methods). This distinction has previously been characterized as *striving for utility* (as in effective artefacts) and *striving for truth* (as in justified theory) (De Villiers & Harpur, 2013; Fallman, 2007; Hevner et al., 2004), and can be compared to the concepts of a *context of discovery* and a *context of justification*, respectively (Hoyningen-Huene, 1987, 2006).

The *design cycle* is concerned with taking insights from theory and practice and coming up with prototypes of increasing sophistication and functionality. The design cycle as such can be viewed as a strategy for devising a potential solution. Within the three cycle-view, however, this design cycle draws from and contributes to the knowledge base (rigor cycle) and field of practice (relevance cycle).

2.2 Phases

This high-level view of design research lacks detail as to which phases and what activities this design cycle should consist of, and how it would produce the relevant outcomes. Serving both utility and truth must be reflected in the relevant type of activities to conduct, and we can identify four distinct research activities. Traditionally, the natural sciences involve *theorizing* what could be true and *justifying* the truth of what was theorized, for example through an experiment. Design engineering and, later, design research expanded these activities by additionally involving the *building* of useful artefacts and *evaluating* the utility of what was built (De Villiers & Harpur, 2013; March & Smith, 1995).

Table 2.1: Three phases of design research with their descriptions.

Phase	Description
Analysis and Exploration	understanding and explication of the problem within its context gaining insight into what is known from literature and practice about possible solutions
Design and Construction	conceiving, designing, and developing a proposed solution that can be used in practice
Evaluation and Reflection	evaluating the solution with members of the target audience

	interpreting the findings and reflecting upon the implications for design

Correspondingly, various proposals for a research-oriented design cycle, and how to subdivide it in iterative phases, have been proposed (Easterday, Lewis, & Gerber, 2014; Easterday et al., 2018; Johannesson & Perjons, 2014; McKenney & Reeves, 2012; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). The main difference between these proposals is the level of granularity and, hence, the number of distinct phases. Following McKenney and Reeves (2012) for the classification of the main phases, and further consulting Johannesson and Perjons (2014) and Easterday (2018) for additional phase descriptions, we define the design cycle phases as shown in Table 2.1. While not necessarily followed in a linear fashion, these phases help to distinguish between different design and research activities and their outcomes.

2.3 Questions

Research is the act of searching closely (French, 1530s, *recerche*) and, consequentially, research is guided by the questions for which it seeks answers. Such questions are colloquially named research questions and tempers may rise over what constitutes a proper research question. The problem is only that much worse if the goal is not only research but also design. During the work on this dissertation, we developed three types of research questions in search of different types of outcomes, as show in Table 2.2.

These design research questions can be closely linked to the four core design research activities (theorizing, justifying, building, and evaluating). The *knowledge questions* will mainly involve theorizing, the *design questions* will be focused on justifying and building, and the *evaluation questions* will revolve around evaluating. The red thread throughout these activities is constructing a rationale for the designed artefacts and learning whether that rationale is justified. The relationships between those activities and these questions are thus not one-on-one. However, these question types do relate closely to the design research phases, with knowledge questions mainly involved during analysis and exploration, design questions during design and construction, and evaluation questions mainly during evaluation and reflection.

Table 2.2: Three types of design research questions with their purpose and some examples.

Question Type	Purpose	Example
Knowledge Question		
describe the acquisition of knowledge from existing theory and practice	seek to select the relevant concepts and provide definitions of and relations between the relevant constructs	What is known from literature and practice about …?
Design Question		
describe the design of concepts, models, and artefacts	seek to yield design principles and design requirements as embodied in artefacts	How can we improve …? How can … be addressed in …?
Evaluation Question		
describe the formative or summative evaluation of designs	seek to answer why or why not the embodied design principles were effective towards their goals	What does … do with …? Is … improved by …?

2.4 Methods

In order to be able to address our aims of identifying relevant design knowledge while contributing to solving an educational problem, we need to be more specific about *how* we will attempt to uncover this design knowledge and *how* this will inform practice. We introduce three methods which we have employed throughout this work.

Analysis of Literature and Practice

An important initial step of design research involves assessing the state-of-the-art. Existing literature in general and existing solutions in specific represent relevant knowledge. We seek to collect this knowledge as generated by the research and designers that have previously addressed similar research and design questions. As discussed, however, the relevant literature is scattered across different disciplines and does not always directly concern the questions and contexts we are studying. Furthermore, this literature is fragmented and often concerns only part of our objectives. Therefore, translation (to our questions and context) and integration (of fragments of knowledge) need to occur before existing knowledge can be presented in a form that is relevant to our research. The practical examples of GBLEs addressing similar issues will need similar translation and integration. Moreover, of such examples we would like to know how they are designed for their purpose – in other words, an additional step of deconstruction is needed to identify the relevant working mechanisms and underlying design principles. A structured qualitative literature review, aimed at identifying design knowledge, accommodates such collection and analysis of the current state-of-the-are in literature in practice.

Experiments to Test Hypotheses

Another part of design research involves the study of artefacts with the objective of testing whether the design of the artefact has the expected and hypothesized effects. This involves conducting an experimental or quasi-experimental study that can draw inferences by comparing how groups of participants are affected by different conditions. While such a formal approach is often not directly associated with design research, we think that design research can benefit from a combination of explorative and confirmative approaches. When previous research provides good reasons to assume that a certain design will contribute to the design objectives, it can be relevant to verify whether that assumption is warranted within the specific context. For example, the effectiveness of a novel training approach could be compared against a more traditional approach (media comparison approach; (Mayer, 2014b)). For design research, however, it may be even more valuable to make comparisons between different configurations of a similar design, to examine which specific design choices are effective (value-added approach; (Mayer, 2014b)). Either way, it is important that the design of the artefact and its relation to the artefact is clear. There must be some formalization of the design in terms of what the working mechanisms for each of the design objectives are and what the underlying rationale of creating the design is.

Experiments to Construct Knowledge

An important part of constructing knowledge through design research involves conducting *design experiments*. Such experiments sample different possible design configurations and can quickly reject bad designs and thus increase the likelihood of finding good ones (Bang & Eriksen, 2014; Binder & Redström, 2006; Easterday et al., 2014). Through the construction of artefacts, design researchers make propositions of 'what could be' (i.e., a proposed design configuration) and through the evaluation of such artefacts they make inferences towards 'what should be' (i.e., a preferred design configuration) (Binder, 2019; Zimmerman & Forlizzi, 2008). In this way, an artefact is a *prototype* of some imagined final product: it allows exploration of some aspects of that future artefact without completing all other relevant aspects. In particular, it allows a focus on exploring the most relevant open design questions (Houde & Hill, 1997).

Correspondingly, the role of prototypes in design research is predominantly as a vehicle for inquiry (Wensveen & Matthews, 2014). Through conducting design experiments, we attempt to learn about the underlying assumptions of the design of the prototype. As such, design experiments contribute to building theory (Bang & Eriksen, 2014; Zimmerman, Forlizzi, & Evenson, 2007), but we do not expect the outcomes to contribute to informing theory in a direct way. Rather, we seek to contribute at the level of *intermediate-level design knowledge*: design knowledge that is more abstracted than particular instantiations, without aspiring to be at the scope of generalized theories (Höök & Löwgren, 2012).

2.5 Outcomes

In order to be able to address our aims of identifying relevant design knowledge while contributing to solving an educational problem, we also need to be more specific about what *form* of design knowledge and what *form* of solutions we are looking for.

The design research process produces four different types of outcomes: concepts, models, methods, and instantiations (De Villiers & Harpur, 2013; Hevner et al., 2004; Johannesson & Perjons, 2014; March & Smith, 1995). These outcomes of design research take the form of contributions to knowledge (e.g., a model to describe the relevant factors in the design of GBLEs) and contributions to practice (e.g., a GBLE that improves 8th-grade science learning), but often concern both (see Table 2.3).

Table 2.3: *Four different types of outcomes of design research with examples of their contributions.*

Outcome	**Example Knowledge Contribution**	**Example Practical Contribution**
Construct		
constructs are the terms, notations, definitions, and concepts that required to formulate problems and possible solutions within the domain of research (definitional knowledge)	a definition of game-based learning	a set of game elements that can be used to foster learning
Model		
models are representations of (parts of) possible solutions and prescribe the structure of (parts of) other artefacts using the constructs (descriptive and prescriptive knowledge)	a set of design dimensions and guidelines that inform the design of metacognitive training	design of a metacognitive training tool that improves learning
Method		
methods are the processes prescribing how to create artefacts (prescriptive and procedural knowledge)	a formalized method to design game-based learning environments for metacognition	a set of steps for designing metacognitive activities
Instantiation		
instantiations are working systems that can be used in practice (embedded knowledge)	a game-based learning environment embedding metacognitive training mechanisms	a game-based learning environment effectively training metacognition

A knowledge contribution is, traditionally speaking, an experimental result, an improvement of existing theory, or a (new) theory in itself. From the perspective of design, however, we are interested in a wider range of knowledge contributions. Any insights anywhere between the abstract, overarching theory on the one hand, and the concrete, instantiated artefact on the other hand, can provide helpful insights for future design. Examples of such intermediate or mid-level design knowledge are strong concepts (Höök & Löwgren, 2012), embodied conjecture (Sandoval, 2004) or formalized design arguments (Easterday et al., 2018; Van den

Akker, Branch, Gustafson, Nieveen, & Plomp, 1999). Although these types of knowledge may be much more contextually sensitive than general theories, at least for exactly those contexts they provide meaningful and helpful advice.

A practical contribution is an idea, a prototype, a product or a fully completed, implemented, and operational educational intervention. This does not imply that all phases and activities circumnavigate the same artefact: a prototype can be built for the sole purpose of testing a theoretical concept, of which the results can be used to inform the building of an actually useful product. The eventual product needs not to be physically based upon previous prototypes, but should definitely be informed by them and their corresponding evaluation results.

3. Research Design

In this final section we present the research design for this dissertation. We first define the research scope, objective, and main research question. We then provide an overview by linking the phases of our research to the research questions, methods, and outcomes of our research. We conclude with an outline of the dissertation in the form of a research flow.

3.1 Research Scope

The scope of this dissertation is to describe the research steps and corresponding results that, together, represent our investigation of designing GBLEs that promotes metacognition in learners, and the formalized design recommendations resulting from this exercise. The dissertation describes this endeavor from an initial literature review through to the iterative exploration, design, construction, and evaluation of GBLEs for metacognition.

3.2 Research Objective and Main Question

With our research we seek to achieve two objectives:

(i) to *gather and synthesize design knowledge*, across different disciplines and from existent and new research, to further the understanding of the design of game-based learning environments for metacognition

(ii) to *apply and evaluate design knowledge* in real-world educational settings, through the conceptualization and construction of prototypes, and by collecting insights about students using them

As such, we hope to help future researchers, designers, as well as students.

The main research question for this dissertation, in correspondence to the research objective, is:

> *How can we design effective game-based learning environments to improve metacognition of learners in higher education?*

The main research question links to both parts of the research objective, as we will address it by designing and constructing GBLEs and learn about how they affect learners through evaluations. As we gain knowledge through the creation and evaluation of designs in the form of instantiations, we will want to use this knowledge iteratively to inform the creation and evaluation of improved designs and instantiations.

3.3 Research Flow and Outline

The main research question is subdivided into a number of questions that, together, contribute to answering the main question. These questions are organized in terms of the phases, question types, and outcome types of design research to create an overview of our research.

In the previous Chapter 1, we have introduced the problem, context, and background for this dissertation and provided conceptual models for the key constructs of metacognition and GBL. In the current Chapter 2, we have introduced the research methodology of design research and its corresponding concepts and processes.

The research flow shown in Figure 2.2 indicates how each consecutive chapter contributes to generating design knowledge by applying research methods to answer knowledge questions, design questions, and evaluation question (central column). In the coming chapters, we build towards a design framework, and associated design principles and design recommendations, that aid future designers and researchers.

Chapter 3 and Chapter 4 concern the *Analysis & Exploration* phase of research. Here, the objective is to synthesize current insights on designing GBLEs and training metacognition in a way that reduces the design complexity for designers. The main outcome of this phase is a design framework describing the design space for GBLEs that address metacognition.

In Chapter 3 (see Figure 2.2, middle left), we present a qualitative review of the current literature on the design of GBLEs that promote metacognition in learners. From the analysis of existing GBLEs and their representation and evaluation as reported in literature, we identify relevant initial design insights. In particular, we further elaborate the relevant concepts and formulate types of metacognitive mechanisms and integration methods for GBL. We discuss the implications for design and research.

In Chapter 4 (see Figure 2.2, bottom left), we present the development of a design framework for digital game-based metacognitive training. Based on the outcomes of the literature review, we propose a design framework for metacognition in GBL consisting of dimensions that describe the relevant areas of the design space. The design framework addresses the design of metacognitive instruction, the design of gameplay, and the combination of both. With the aim of verifying the merit of the design framework, we apply the design framework to five existing cases selected from Chapter 3 and conduct a formative evaluation of the framework through expert reviews and thematic analysis.

In Chapters 5 and Chapter 6 we discuss studies that fall in the *Design & Construction* and *Evaluation & Reflection* phases. Here, the objective is to specifically formulate and verify insights about how the design of the GBLE affects learners and learning. For this purpose, the design framework will be applied to various GBLE-designs. The main outcomes are design principles and recommendations that augment the design framework.

In Chapter 5 (see Figure 2.2, top right), we present an experiment that focuses on the design of digital metacognitive instruction. We first derive a conceptual model of metacognition during self-regulated learning and, together with the design framework from Chapter 4, use it to inform the design of a digital tool. This digital tool introduces self-explication as a metacognitive mechanism. The experiment in this chapter concerns the effectiveness of this mechanism to improve metacognition and learning, as well as the perceptions learners have on using such a tool. Furthermore, we explore whether a domain-general and detached approach to metacognitive training is viable.

In Chapter 6 (see Figure 2.2, bottom right), we explore the use of gameplay to promote metacognition and metacognitive training in learners. Throughout a series of design experiments, and using the dimensions of the design framework as a guide, we sample the design space with instantiations. In particular, we formulate the design principles with which these instantiations are created. Throughout the design experiments, we learn by evaluating the perceptions of learners in real-world educational settings and the impact on metacognition and learning over longer periods of time. From the series of design experiments as a whole, we further derive design recommendations.

We will come back to, and elaborate in more detail, the contribution of each chapter in terms of the research flow at the start of the corresponding chapter.

This dissertation concludes with Chapter 7, in which a general discussion is presented. Here we address, in retrospect, our reflections on outcomes, methods, and future directions for research and practice.

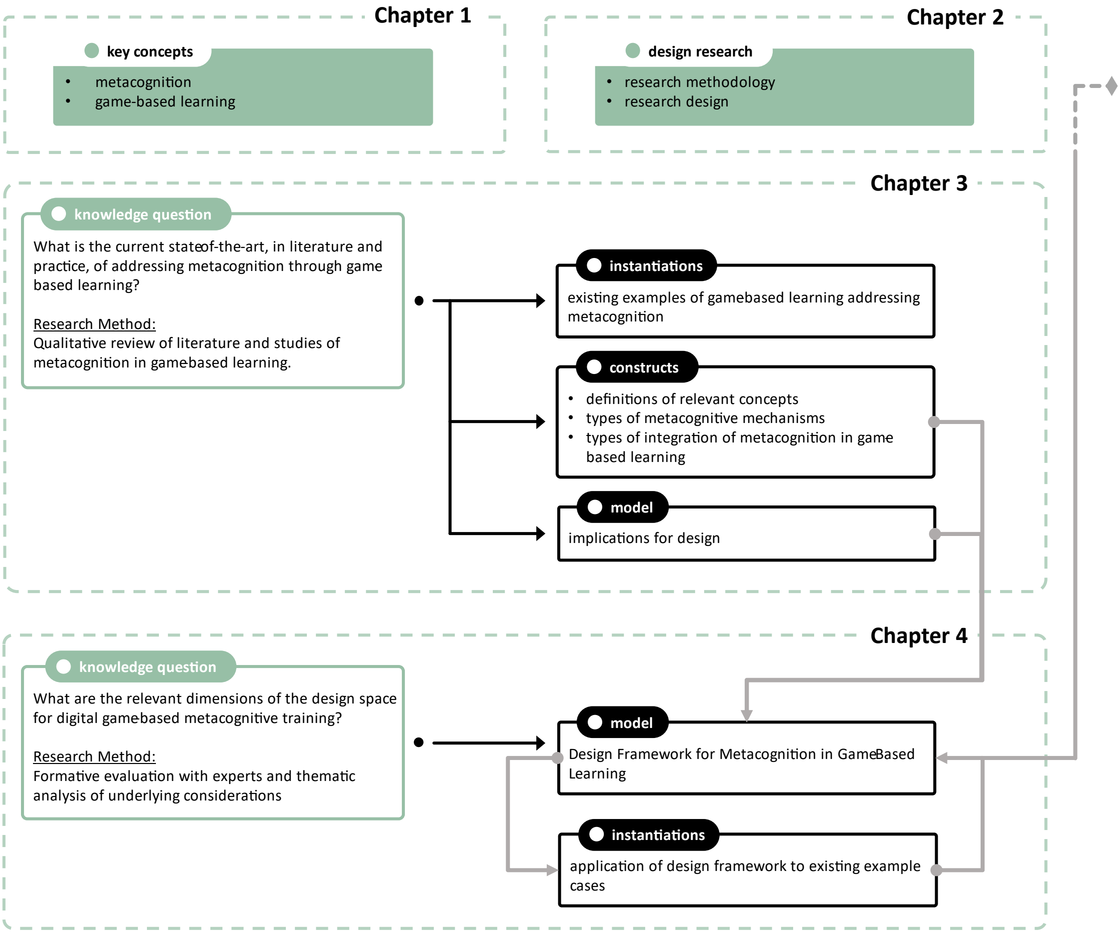
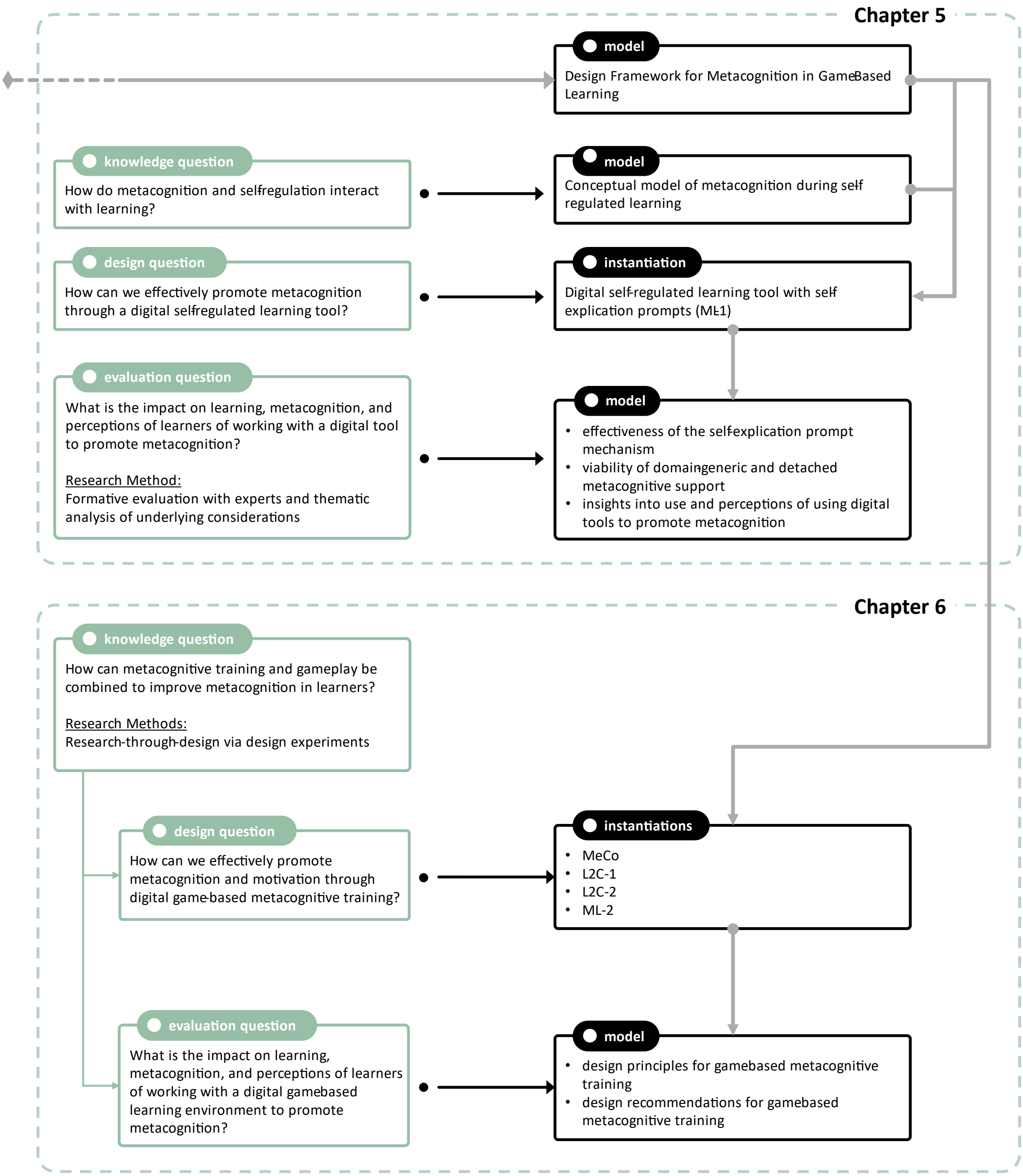


Figure 2.2: research flow.


Chapter 5
model
Design Framework for Metacognition in Game-Based Learning
knowledge question
How do metacognition and self-regulation interact with learning?
model
Conceptual model of metacognition during self-regulated learning
design question
How can we effectively promote metacognition through a digital self-regulated learning tool?
instantiation
Digital self-regulated learning tool with self-explication prompts (ML-1)
evaluation question
What is the impact on learning, metacognition, and perceptions of learners of working with a digital tool to promote metacognition?
Research Method:
Formative evaluation with experts and thematic analysis of underlying considerations
model
effectiveness of the self-explication prompt mechanism
viability of domain-generic and detached metacognitive support
insights into use and perceptions of using digital tools to promote metacognition
Chapter 6
knowledge question
How can metacognitive training and gameplay be combined to improve metacognition in learners?
Research Methods:
Research-through-design via design experiments
design question
How can we effectively promote metacognition and motivation through digital game-based metacognitive training?
instantiations
MeCo
L2C-1
L2C-2
ML-2
evaluation question
What is the impact on learning, metacognition, and perceptions of learners of working with a digital game-based learning environment to promote metacognition?
model
design principles for game-based metacognitive training
design recommendations for game-based metacognitive training

chapter three

Qualitative Review

This chapter is based on the following journal paper:

Braad, E., Degens, N., & IJsselsteijn, W.A. (2020). Designing for metacognition in game-based learning: A qualitative review. *Translational Issues in Psychological Science*, *6*(1), 53—69.

Abstract and Research Flow

GBL is an interactive form of training in which instructional elements are combined with motivational elements within one GBLE. Under the right circumstances, GBL can contribute to both learning and motivation. It is however unclear which elements in the design of GBLEs can encourage effective and efficient learning.

Metacognition is cognition about cognition: knowing about one's own knowledge and applying that knowledge in practice. While research has found that learners can benefit from metacognitive support within learning environments, it is unclear how to encourage metacognition in GBLEs to improve learning effectively and efficiently.

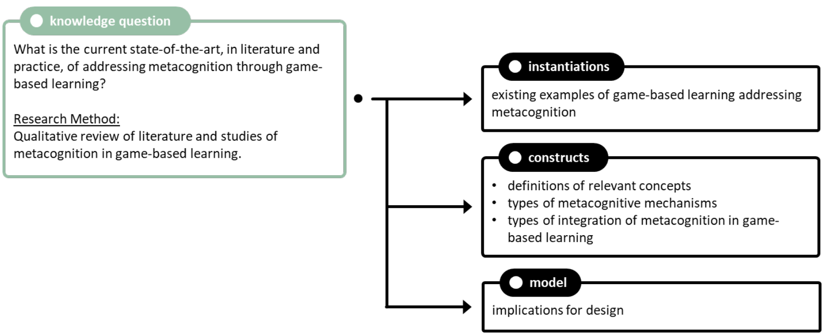


Figure 3.1: research flow for Chapter 3.

In this chapter, we present a qualitative review of metacognition within GBL. We discuss the objectives, mechanisms, and effects reported in studies that address metacognition in GBLEs. The aim of this review is to inform educational designers, researchers, and other professionals who want to address metacognition in GBL, and the review concludes with concrete implications for design and research. As such, this chapter contributes to collecting examples, defining the relevant concepts, identifying types of metacognitive mechanisms and types of integration GBL, and initial implications for design (see Figure 3.1).

1. Introduction

GBL is an active form of learning that may include a variety of learning events (e.g., instruction, practice, feedback, and assessment) and a variety of motivational elements (e.g., challenge, rewards, and fantasy). While various meta-reviews showed that GBL can indeed contribute to both learning and motivation (Boyle et al., 2016; Wouters et al., 2013), it remains unclear how learners learn effectively and efficiently through interactions with GBLEs and which elements in the design of GBLEs promote learning and motivation (Boyle et al., 2016; Ke, 2016). As a result, it is difficult for designers and researchers to make informed design decisions when creating such learning environments.

Metacognition, or cognition about cognition, refers to knowledge about one's own knowledge and the application of that knowledge in the practice of learning. One of the reasons that GBL is not always effective may lie in that complex learning environments place a high demand on the metacognitive abilities of learners (Azevedo, 2005b). Not all learners are equally able to metacognitively monitor and regulate their learning, and it may therefore be necessary that any learning environment should include metacognitive mechanisms to support learners (Lin, 2001). While learners sometimes use metacognitive monitoring and regulation spontaneously while learning with games, it is unclear how to actively encourage metacognition through the design of GBLEs (Ke, 2016). Thus, if we want learners to learn effectively and efficiently through GBL, a crucial next step is to examine which design choices in the design of GBLEs can promote metacognitive knowledge, monitoring, and regulation in learners (Ke, 2016; Nietfeld & Shores, 2011; Sitzmann, 2011).

In this chapter, we present a qualitative review of metacognition within GBL. The goal of this review is to inform educational designers, psychologists, researchers, and other professionals who want to address metacognition in GBL. The focus in this review is on how to design GBLEs to encourage metacognition and hence the review concludes with concrete implications for the design and future research of metacognition in GBLEs.

2. Background

2.1 Metacognition

Metacognition is cognition about cognition: knowing about one's own knowledge and applying that knowledge in practice (Flavell, 1979). In the context of learning, it refers to what learners know about learning and how they use that knowledge to monitor and regulate their learning (Brown, 1978). Metacognition is the most important learner factor that positively impacts academic performance, even outweighing intelligence (Veenman & Spaans, 2005), warranting research into how metacognition can be promoted in learners.

While the concept itself is diffuse and prone to inconsistent terminology (Moshman, 2018), most researchers agree that metacognition consists of metacognitive knowledge and metacognitive skills. Metacognitive knowledge refers to the declarative, procedural, and conditional knowledge a person has about learning (Jacobs & Paris, 1987; Schraw, 1998), such as knowing different learning strategies and knowing when a learning strategy is suitable for a specific learning task. Metacognitive skills comprise the set of cognitive processes through which metacognitive knowledge is applied to learning, most notably through monitoring and regulation. Monitoring refers to inspecting how learning is proceeding, for example by making judgments of learning (e.g., how much have I learned so far) or estimating confidence (e.g., how confident am I that what I know is correct). Regulation refers to using such observations to control learning, for example by applying strategies, selecting and executing learning activities, and other cognitively driven actions (Schraw & Moshman, 1995).

Metacognition is often considered specific to a domain of learning (e.g., reading comprehension, mathematics) or specific to a learning task (e.g., reading a text, solving an equation), although increasing evidence exists for domain-general aspects of metacognition (Veenman et al., 2006). While metacognition may be partially tacit or automatic for some learners, the construct generally refers to a conscious understanding of how to learn, as emphasized in the term metacognitive awareness (Schraw, 1998). For the remainder of this chapter, we will use metacognition to refer to metacognitive awareness and its components of metacognitive knowledge and skills.

Metacognition may be learnt implicitly but can also be enhanced through direct instruction or indirect metacognitive support (Veenman et al., 2006). Examples of such instructional or supportive mechanisms are metacognitive scaffolding, that provides concrete help to learners (direct instruction), and metacognitive prompting, that cues learners to monitor or regulate their learning (indirect instruction). For this review, we define a metacognitive mechanism as any mechanism through which metacognition is promoted within a learning environment.

2.2 Digital Game-Based Learning

Digital game-based learning refers to learning through interaction with a digital game. A game can be defined as a system in which players engage in artificial conflict, defined by rules, and resulting in a quantifiable outcome (Salen & Zimmerman, 2004). GBL is based on the idea that games can be designed to promote specific learning outcomes through interactive play (Plass et al., 2015). While learning content could be presented separately from game content, both learning and motivation are positively impacted if playing and learning are intrinsically integrated and aligned (Habgood & Ainsworth, 2011). Learners may learn from games by experimenting and practicing in a safe and risk-free environment, by receiving direct and indirect feedback, and by debriefing and reflecting on the playthrough (Garris et al., 2002). Learners may be motivated to begin and continue learning through game design elements such as challenge, control, rewards, curiosity, fantasy, cooperation, and competition (Malone & Lepper, 1987). The instructional and motivational elements of GBL are not necessarily part of the game. Therefore, we will use the broader term game-based learning environment (GBLE) to refer to the environment the learner interacts with.

Learning through playing is promoted through game design elements as part of an interactive game loop of goals or challenges set for the player by the game, actions performed by the player, and feedback and rewards provided by the game in return (Dondlinger, 2007; Garris et al., 2002; Plass et al., 2015). This loop is characterized by rules that dictate which actions are allowed, core mechanics that determine which responses the game gives to these actions, and is often framed within a narrative setting that provides fantasy and aids understanding and meaning-making for the player (Dickey, 2006; Dondlinger, 2007). Finally, social aspects of gaming can contribute to both learning and motivation, for example through online or offline multiplayer games and by observing others while playing (Gajadhar, De Kort, & IJsselsteijn, 2008).

2.3 Metacognition in Game-Based Learning

Computer-based learning environments in general can be viewed as metacognitive tools for enhancing learning (Azevedo, 2005a, 2005b; Azevedo et al., 2012). GBLEs in particular may be suitable for encouraging metacognition, as learners are involved as active participants in learning (Sitzmann, 2011). Previous research has suggested potentially effective metacognitive mechanisms for GBL, such as adaptive scaffolding, collaboration, and self-explanation (Nietfeld & Shores, 2011). More recently, generic metacognitive design principles for GBL, such as self-explanation, reflection, feedback, and guided practice have been proposed (Mayer, 2016). However, a comprehensive overview that informs the design and research of GBLEs for metacognition is currently lacking.

The challenges in designing GBLEs that encourage metacognition can be summarized as follows. First, it is currently unclear which metacognitive objectives are suitable to address through GBL. Second, given such a metacognitive objective, it is currently unclear which metacognitive mechanisms within the GBLE can address this objective and how to combine such mechanisms with gameplay. Third, and last, it is currently unclear which approaches towards encouraging metacognition in GBL are effective. In summary, insights are needed that relate metacognitive objectives to effective metacognitive mechanisms and ways of aligning and integrating such mechanisms with the gameplay.

3. Approach

The goal of this chapter is to address these challenges by collecting and analyzing studies that attempt to encourage metacognition through mechanisms in GBLEs. We seek to identify implications that can guide designers and researchers of GBLEs. For designers of GBLEs, we want to identify the design choices that have a positive impact on metacognition and learning outcomes. For researchers, we want to identify the gaps that need to be addressed to advance insights on metacognition in relation to GBL.

The challenges in designing GBL for metacognition are addressed by three review questions that guide our search and analysis. The first review question focuses on identifying what the study tried to achieve regarding metacognition of learners, while the second review question focuses on the working mechanisms proposed to achieve this. The third and final review question then focuses on how these mechanisms were evaluated and which effects were found. The review questions are formulated as follows:

(1) What were the metacognitive objectives of the game-based learning environment?

(2) Which metacognitive mechanisms were implemented to address these objectives?

(3) How were these metacognitive mechanisms evaluated and which effects were found?

An initial literature search revealed that no previous meta-analyses of metacognition in GBL have been published to date, warranting a wide literature search. The WorldCat database, including ACM, APA, ERIC and IEEE, was queried using the search terms game(s), gaming, or simulation(s) combined with metacognition, metacognitive, cognition and monitoring, and learning and regulation, and Google Scholar was used to corroborate and augment our results.

The coding and selection process, as shown in Figure 3.2, yielded 24 publications describing 27 studies included in this review (see Appendix A for an overview of the selected publications).

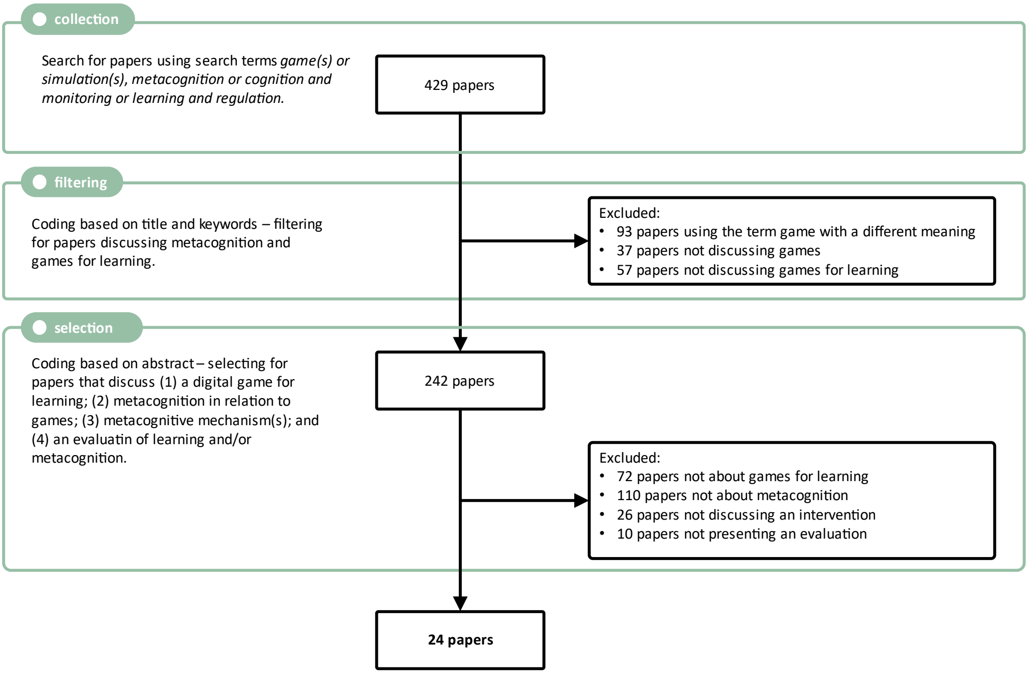


Figure 3.2: Search procedure, selection criteria, and number of included and excluded papers in each step.

Table 3.1:Description of the selected studies in terms of the audience and objectives, metacognitive mechanisms, design of the study, measurements taken, and results found from the evaluation.

#	Audience and Objectives	Mechanisms	Study Design	Measurements	Evaluation Results
1	college students (domain general): improve cognitive bias knowledge and mitigation	· direct/hybrid instruction · self-evaluation (quiz) · performance-based adaptive instruction	between-subjects experiment (N=703) 1x or 2x 30 min. over 2 wks. with post-test after 8 wks.	metacognitive knowledge and skills (questionnaires)	metacognitive knowledge increased and remained higher at delayed post-test under both intervention and repeated play (vs. control group)
2	college students (domain general): improve cognitive bias knowledge and mitigation	as in exp. 1, plus immediate (vs. delayed) metacognitive feedback	between-subjects experiment (N=620) 1x or 2x 30 min. over 2 wks. with post-test after 8 wks.	metacognitive knowledge and skills (questionnaires)	feedback did not make a discernible difference
3	college students (domain general): improve cognitive bias knowledge and mitigation	as in exp. 2, plus single- (vs. multi-)player modes	between-subjects experiment (N=626) 1x or 2x 30 min. over 2 wks. with post-test after 8 wks.	metacognitive knowledge and skills (questionnaires)	social structure did not make a discernible difference
4	college students in engineering: metacognitive monitoring to enhance learning	metacognitive prompt to self-explain	between-subjects quasi-experiment (N=65) +/- 3 days	metacognition (questionnaire)	positive impact of metacognitive prompting on learning
5	college students in game development: improve metacognitive knowledge	in-game metaphors to real-life learning	user study/preliminary evaluation 5-week period	user feedback (log data, questionnaires)	positive user feedback but no metacognitive evaluation
6	4th-grade students in language learning: planning and monitoring to enhance learning	scaffolding by visualization of learning status	between-subjects pre-test/post-test quasi-experiment (N=30) 2x 35 min. over 2 wks.	domain learning performance (knowledge test), metacognitive skills (questionnaire)	· learning performance increased significantly and similarly in both conditions · interventions significantly enhanced metacognitive skills (planning and monitoring)
7	adults in health care: reflection	metacognitive prompt to reflect	user study/preliminary evaluation single session; length not reported	user feedback (questionnaires, interviews)	reflection questions were regarded as positive and relevant

#	Audience and Objectives	Mechanisms	Study Design	Measurements	Evaluation Results
8	college students in physics: attention direction and reflection to enhance learning	· worksheet to focus on specific elements · worksheet linking game features to learning goals	between-subjects experiment (N=50) 1x 30 min. single session	domain learning performance (embedded knowledge test, questionnaires)	· learning performance higher and perceived difficulty lower at direct post-test (vs. control group) · no increase in self-reported effort (vs. control group) · increased self-reported satisfaction (vs. control group)
9	college students in physics: attention direction and reflection to enhance learning	· worksheet to focus on specific elements · worksheet linking game features to learning goals	between-subjects experiment (N=114) 1x 30 min. single session	domain learning performance (embedded knowledge test, questionnaires)	· learning performance not different between groups · learning performance of high-performing students increased (vs. low-performing students in experimental group)
10	computer science students: reflection	one-on-one in-game competition	user study/preliminary evaluation 2 hours, 2-3 times/week	metacognition, learning performance (observation and field notes)	some indications of inspiring metacognition in learners
11	adults (domain-general): improve cognitive adaptability	· shifting rules and environments · open-ended gameplay	between-subjects experiment (N=39) 12 hrs. over 2 days.	metacognition (questionnaire)	no significant effect found
12	5th- and 6th grade students in physics: metacognitive skills to enhance learning	· process scaffold (checklist) · metacognitive prompts to cue behavior	within-subjects pre-test/post-test experiment (N=20) 30 min. single session	domain learning performance (knowledge test), metacognitive skills (questionnaire)	· significant increase in domain learning performance · non-significant increase in metacognitive skills
13	4th- and 5th-grade students in mathematics: metacognitive awareness to enhance learning	iterative application, testing, and revision of skills in game	within-subjects pre-test/post-test experiment (N=15) 10x 2 hrs. over 5 wks.	metacognition, learning, motivation (questionnaires)	· no significant effect of computer games on learning or metacognitive knowledge · significant increase in learning attitude
14	5th-grade students in mathematics: metacognitive awareness to enhance learning	· games (vs. paper-and-pencil drills) · collaboration (vs. individual or competitive setting)	between-subjects quasi-experiment (N=487) 2x 45 min. p/wk. over 4 wks.	metacognition, learning, motivation (observation, think aloud, questionnaires)	· games were more motivating (vs. paper/pencil drills) but did not improve performance or metacognitive awareness · collaborative setting enhanced the effect of games on motivation but did not affect performance or metacognitive awareness

#	Audience and Objectives	Mechanisms	Study Design	Measurements	Evaluation Results
15	9th-grade students in finance: metacognitive strategies to enhance learning	direct instruction	within-subjects pre-test/post-test experiment (N=132) 2x 45 min. per wk. for 10 wks.	learning (questionnaires, knowledge test)	learning performance increased
16	6th-grade students in mathematics: improve metacognitive awareness	· game challenge · scaffolding (worked examples comparison)	between-subjects quasi-experiment (N=86) 285 min. over 4 wks.	metacognition (questionnaire), domain learning performance (test)	significant higher performance for game challenge with scaffolding (vs. either game challenge or scaffolding alone)
17	high school students (reading comprehension): reflection to enhance learning	· performance-based adaptive transfer · self-explanation	between-subjects experiment (N=234) 5 sessions over 3 days	metacognition (log data), domain learning performance (transfer test)	no significant results for adaptive transfer or self-explanation on comprehension or transfer
18	secondary school students in physics: metacognitive strategies to enhance learning	direct instruction (vs. scaffolding)	between-subjects experiment (N=99) 90 min. of which 20 min. of interaction; single session	metacognition, motivation (questionnaire), domain learning performance (knowledge test)	· no main effects for training and prompting, and no interaction effect · for 20 participants who used prompting appropriately, learning performance increased significantly
19	adults (intercultural competence): improve metacognitive agility	reflective observation role	user study/preliminary evaluation 0-5 hours over 3-month period	user feedback (questionnaires, focus groups)	no evaluation of effects on learning or metacognition
20	college students (incident commanders): improve metacognitive reflection	rewind-and-redo from point-of-error mechanic	exploratory study (N=15) single session; length not reported	metacognition, learning (observations, interviews, questionnaires)	qualitative analysis suggests increase in metacognitive awareness
21	college students in reading comprehension: improve metacognitive awareness	· performance-based metacognitive feedback · performance-based adaptive transfer	within-subjects pre-test/post-test experiment (N=28) 1 hr. single session	metacognition (log data)	automatically computed self-explanation quality increased
22	5th-grade students in philosophy: improve metacognitive strategies	direct instruction	between-subjects experiment (N=49) 90 min.	metacognition, domain learning performance, motivation (questionnaires)	enhanced learning as well as increased (deep) strategy use
23	vocational students in physics: metacognitive monitoring and regulation to enhance learning	metacognitive tools supporting task structure, problem-solving and social interaction	between-subjects pre-test/post-test experiment (N=39) time not reported	learning, motivation (questionnaires, focus groups)	· self-reported proficiency significantly higher when using metacognitive tools · qualitative feedback: tool purpose and use needs to be cued or explained

#	Audience and Objectives	Mechanisms	Study Design	Measurements	Evaluation Results
24	vocational students in engineering: metacognitive awareness to enhance learning	metacognitive tools supporting task structure, problem-solving and social interaction	user study/preliminary evaluation (N=15) time not reported	user feedback (questionnaire)	· students did not always understand how to access or use the metacognitive tools · some of the comments do indicate reflection on learning
25	adults in chemistry: metacognitive level to enhance learning	games conceptualized as the intervention itself	between-subjects experiment (N=176) with post hoc within-subjects analysis 8-week period	metacognition, learning performance, motivation (questionnaires)	· no significant difference between groups · non-significant raise in metacognition within-subject between pre- and post-test)
26	adults in finance: confidence estimation to enhance learning	· metacognitive prompts to explicate confidence · collaborative (vs. individual) discussion of confidence	between-subjects quasi-experiment (N=16) 25 min. single session	metacognition (questionnaires, log data, observation), learning (test, log data)	no significant results for performance or feeling-of-knowing evolution
27	college students in physics: improve accuracy of confidence estimation	· give confidence ratings for answers · feedback on confidence rating accuracy	within-subjects pre-test/post-test experiment (N=28) 20 min. single session	metacognition (questionnaire), learning (embedded test, questionnaires)	· increase in confidence accuracy · mixed results on learning performance

4. Results and Discussion

4.1 Results

The included studies are summarized in Table 3.1. The results are further discussed in the subsequent sections, as organized by the three review questions.

Objectives

There is ongoing debate about what is and what is not metacognition, which is reflected in the widely differing terms and definitions of metacognition used. While most studies referred to metacognitive awareness or its components of metacognitive knowledge, monitoring, or regulation, some studies introduced new constructs such as 'metacognitive agility', 'cognitive adaptability', or 'metacognitive level'. We agree with Moshman (2018) that a shared and specific way of defining and describing metacognitive objectives is necessary, which must also be practically applicable for designers and researchers. Such an objective would be described in terms of the expected effects on learners' metacognition, in a testable way, and in relation to the mechanisms within the learning environment that promote these effects.

- **Research Implication**: More formalized ways of specifying and comparing metacognitive objectives need to be developed.
- **Design Implication**: Metacognitive objectives must be formulated in terms of the expected effects on learning and learners in a testable way.

We further found two distinctions that can improve clarity of the metacognitive objectives. First, the role of promoting metacognition can be either to enhance current learning, or to enhance future learning. If the objective is to enhance current learning, then metacognitive mechanisms must be designed to enable learners to increase the effectiveness and efficiency with which they can achieve the domain learning goals – for example, by scaffolding the problem-solving process or prompting for self-explanation of current understanding. If, on the other hand, the objective is to enhance future learning, then metacognitive mechanisms must be designed such that learners are able to improve their metacognitive knowledge and skills – for example, by prompting for self-explication of the current learning strategy. Additionally, learners must be enabled to transfer these metacognitive gains to future learning situations. Second, generality of metacognition can be either domain-specific or domain-general. If the objective is to encourage domain-specific metacognition, then the GBLE needs to be designed in a way that emphasizes the domain-specific learning content and supports learners in metacognitively processing that content. If, on the other hand, the objective is to encourage domain-general metacognition, then the GBLE needs to be designed in a way that helps learners to apply domain-general metacognition to concrete domain-specific learning – for example by detaching metacognitive training from domain-specific training but providing heuristics for when and where to use the metacognitive aspects being trained.

In summary, the description of metacognitive objectives should not only include a proper definition of metacognition (e.g., knowledge, skills, awareness), but also the role of metacognition (i.e., enhancing current or future learning) and the domain-generality of metacognition (i.e., domain-specific or domain-general).

- **Design Implication**: Metacognitive objectives must be formulated in terms of the definition, the role, and the domain-generality of metacognition.

Mechanisms

The terminology used to describe the different metacognitive mechanisms in the selected studies varies widely. This makes it hard to transfer knowledge gained from individual case studies to inform future designs, as it is hard to compare similar mechanisms that are named and described differently. In other words, without a shared way of specifying and comparing metacognitive mechanisms and the underlying design guidelines, it remains hard to extract generalized knowledge from case-by-case research findings and apply it to other GBLEs.

Table 3.2: Overview of metacognitive mechanism types for game-based learning.

Mechanism Type	Description	Studies
direct instruction	Definition: instructing learners directly about metacognition. Example: metacognitive strategy training before learning activities.	1, 15, 22
adaptive instruction	Definition: altering the instruction, support or feedback based on learner behavior. Example: transferring underperforming learners to remedial activities.	1, 17
metacognitive cues	Definition: reminding students to perform metacognitive activities while learning. Example: asking learners to reflect on their current learning strategy.	7, 18
metacognitive scaffolds	Definition: providing learners with supports that make it easier to apply metacognition Example: providing (partial) worked examples for comparison.	6, 8, 9, 12, 16, 18, 23, 24
self-explanation	Definition: making current learning progress explicit by expressing it Example: asking learners to describe their current understanding of the domain learning content.	1, 4, 8, 17
self-explication	Definition: making metacognitive processes explicit by expressing them. Example: entering a degree of confidence in answer correctness when giving that answer.	9, 26, 27
metacognitive feedback	Definition: providing learners with feedback on their metacognitive activities. Example: displaying how accurate confidence explications are.	2, 27
social interaction	Definition: using the interaction with others to support metacognitive activities. Example: comparing and discussing confidence explications before giving an answer.	3, 14,1 9, 23, 24, 26
game design features	Definition: employing specific game design features to encourage metacognition in learners. Example: using cooperative or competitive multiplayer modes between players.	3, 5, 10, 11, 13, 14, 16, 20, 25, 27

Further analysis on the purpose of the mechanisms allowed us to group the collected studies into nine types of metacognitive mechanism for GBL. This notably excludes prompting as a single mechanism type, since prompts can be used for different purposes such as cueing, scaffolding, or self-explication. An initial overview of metacognitive mechanisms for GBL, with their definitions, examples, and studies that discuss them, are shown in Table 3.2. However, further research is needed to identify which type of mechanism is (most) suitable for which type of metacognitive objective.

- **Research Implication**: More formalized ways of specifying and comparing metacognitive mechanisms need to be developed.

The term game is used to refer to a wide range of GBLEs: from basic multiple-choice quiz games to immersive 3D-environments with a wide range of goals, mechanics, narrative elements, and social interactions. Various game design elements are suggested for encouraging metacognition, such as competition, challenge, use of metaphors, the dynamic changing of rules and environments, and multiplayer interactions.

We identified two design implications that aid the design of GBLEs for metacognition. First, almost all the games in the selected studies adopt a step-by-step, deliberate style of gameplay, as opposed to time-based, action-packed, reactive gameplay. This allows players to consciously consider, select and evaluate actions and outcomes at their own pace; an important prerequisite for metacognitive monitoring and reflection. Second, the GBLEs differ in how much freedom a player has to choose actions. A few games even try to adapt the game activities to the individual needs of the player, by suggesting or presenting different game activities. Striking the right balance between enough freedom to practice and enough guidance to apply metacognition effectively to learning is a key design goal for metacognitive mechanisms in GBL. Apart from these two initial design implications, further research is needed to identify applicable design guidelines for designing gameplay that encourages metacognition in learners.

- **Design Implication**: Adopt deliberate step-by-step gameplay.
- **Design Implication**: Adaptively balance freedom and guidance.

- **Research Implication**: Further research is needed to identify guidelines for designing gameplay to encourage metacognition.

Literature suggests that learning and motivation are positively impacted by designing GBLEs such that learning and playing are intrinsically integrated and aligned. Few studies attempt such intrinsic integration, for example by designing the narrative and mechanics such that they contribute to encouraging metacognition. However, in most studies, metacognitive mechanisms are introduced without relating them to the gameplay itself.

Table 3.3: Three integration approaches for metacognitive mechanisms in GBLEs.

Integration	Description	Studies
exogenous	Definition: metacognitive mechanism is not part of or related to the gameplay or game environment Example: metacognitive strategy instruction before game-based learning activities.	8, 9, 13, 14, 15, 19
extrinsic	Definition: metacognitive mechanism is part of the game environment but not related to the gameplay Example: process-scaffolding tools to keep track of problem-solving steps	4, 6, 12, 16, 17, 18 ,21, 23, 24, 26
intrinsic	Definition: metacognitive mechanism is part of the gameplay Example: self-explicating confidence as part of an in-game puzzle.	1, 2, 3, 5, 7, 20, 22, 27

Further analysis allowed us to group the different approaches to integration in three high-level categories of integration: exogenous, extrinsic, and intrinsic integration, as shown in Table 3.3. While intrinsically integrating metacognitive mechanisms with the gameplay is applaudable, it is also more challenging. Metacognitive learning goals require that learners examine their own thoughts, tactics, and strategies in the real world, rather than focusing only on actions and responses within the game environment. Therefore, it seems, a metacognitive mechanism is harder to integrate intrinsically into the game design than for other learning goals. Some examples are adopting metacognition as the topic of the game or disguising metacognitive prompts as part of an in-game puzzle. However, such approaches hinge on very specific game design choices that are hard to generalize to other games. A next step for intrinsic integration of metacognitive mechanism would be to examine the dimensions of game design that allow alignment of metacognition with gameplay and to identify generic design guidelines that apply across different cases.

- **Research Implication**: Further research is needed to identify guidelines for intrinsically integrating metacognitive mechanisms with gameplay.

Effects

While literature on addressing metacognition through GBL is increasing, we found only 24 studies that include some form of evaluation, of which six studies are only preliminary studies and the remaining 18 studies reporting mixed results. The studies varied widely in sample size, running time, and whether measurements of learning, metacognition, and/or motivation were analyzed. As metacognition develops slowly over a longer period and in individually different ways and at different rates, studies that run over a longer period are preferred over single-session evaluations. Likewise, more insights can be gained from studies that assess metacognition as a dependent or intermediate variable, instead of only measuring effects on learning performance. In other words, we contend with Veenman et al. (2006) that in addition to measures of learning performance, measures of metacognition itself need to be taken. We add that the effects on motivation must be studied – as learners must be sufficiently motivated to exert the additional effort to add metacognitive processing to domain- and task-level cognitive processing.

- **Research Implication**: Evaluations of metacognitive mechanisms in game-based learning must assess domain learning, metacognition, and motivation.

Only nine studies reported clear and significant effects of the intervention on learning or metacognition. Of these studies, three studies found a positive impact on metacognition, all three the result of some form of direct instruction. The remaining six studies found a positive effect of metacognition on domain-learning performance, most prominently through direct instruction or metacognitive prompting. In short, the quantity and quality of the evidence for metacognition in GBL is currently very limited and there is ample room for experiments that evaluate the effects of different types of metacognitive objectives, different types of metacognitive mechanisms, and different types of integration in games.

- **Research Implication**: Evaluations are needed that assess the impact of metacognitive mechanisms on metacognitive objectives.

While a quantitative meta-analysis is beyond the scope of this review, it appears from the results that more direct mechanisms (e.g., instruction) are more effective than more indirect mechanisms (e.g., feedback). Furthermore, direct instruction, scaffolding, as well as cueing, seem to have a positive impact on enhancing learning as well as on improving metacognition. However, none of the social features were found to have an impact on learning or metacognition. Of the different game design elements suggested for encouraging metacognition, positive effects were found only for game challenge combined with scaffolding, and for embedding of metacognition in the narrative and mechanics of the game. The benefits of integrating mechanisms with gameplay are also not evident from the studies analyzed in this review.

5. Conclusions

In this chapter we have presented a review of metacognition in GBL and have identified important implications for future design and research. Additionally, we have presented an initial overview of metacognitive mechanism types and ways of integrating metacognitive mechanisms with the goals, mechanics, narrative and social elements of the game design. We found that the limited ways in which GBLE-designs can be compared stands in the way of advancing insights across this field. To advance GBL from case-by-case findings towards generalized design guidelines for encouraging metacognition in GBLEs, we need to create insight across different fields, terms, and experimental findings. The overview of metacognitive mechanisms for GBL presented in this chapter, in conjunction with the insights regarding how these mechanisms can be integrated in the GBLE, can be regarded as a first step towards these goals. However, we need to develop more formalized ways to communicate about designs in general and the mechanisms implemented in particular. If we want to advance insight in which mechanisms can be used to help encourage metacognitive knowledge and skills, we must be exact about what it is that we want to promote and how it is promoted.

5.1 Limitations

We have already highlighted the complexities of metacognition as a term: there are many other concepts and constructs that can be viewed as part of metacognition. Therefore, we may have missed studies that address these specific constructs without explicitly referring to the larger construct of metacognition. For example, the broader construct of self-regulated learning encompasses metacognition, but also cognition and motivation, and we refer to a comprehensive review by Nietfeld and Shores (2011) for recommendations regarding self-regulation in GBL. Furthermore, as we have focused on collecting different approaches towards addressing metacognition in GBLEs, we did not conduct a quantitative meta-analysis on which approaches are effective. We also did not distinguish between the different types of learners. However, the limited quality and quantity of current work illustrates the limited potential of such an approach at this point in time. A future review including a meta-analysis of the empirical results from these and other studies may shed further light on which types of mechanisms are particularly effective and for whom. Nonetheless, as the first review to our knowledge that comprehensively addresses both metacognitive objectives and metacognitive mechanisms within GBLEs, we have contributed to advancing design and research in GBL as well as educational psychology and instructional design.

5.2 Future Work

As research on GBL is only in its adolescence, it is no surprise that we find large differences in concepts, definitions, mechanisms, and measurements. We propose three consecutive future directions for GBL: specificity, comparability, and transferability.

Specificity. To advance the efficiency and effectiveness of digital learning environments for learners, we must work towards a clear, shared, and practical view on metacognition as well as GBL. Important questions that can advance the literature base on metacognition in GBL are (i) which aspects of metacognition are specifically relevant to be addressed within GBLEs; (ii) how these aspects can be defined in terms of testable behavior or change within learners; and (iii) how these aspects could be captured by a combination of online and offline measurements. Important insights for advancing research of GBL are (i) being specific about which elements are included in the design; (ii) for what purpose (e.g., to motivate, to teach, to support practice, etc.); and (iii) how these elements contribute to this purpose. At that point, it is not so much relevant whether something is or is not a game, but to what extent motivation and learning are impacted by interactive elements within the design of the learning environment.

Comparability. In order to develop generic design knowledge on how to improve learning within GBLEs, it is paramount to be able to compare different approaches and systems. We propose that further formalization of the design of digital learning environments could contribute towards this goal. Such a formalization would allow us to define the different components and their functions, describe relationships and interaction between components, and, most importantly, describe how the interaction between learner and system contributes to learning.

Transferability. From the available case-by-case evidence, it is hard to distinguish between specific design choices made in one instance and design guidelines that can be applied in general. This hampers the transfer of knowledge from specific cases towards other, current and future, designs of learning environments. If we find ways of more specifically defining the concepts we address, and can compare different designs systematically, we can work towards transferring the critical design decisions in effective designs to future designs.

To advance GBL, a multidisciplinary effort, involving expertise from educational psychologists, instructional designers, and experts in GBL and game design is required. The lens of metacognition is a particularly important lens, as it addresses the study of learning itself by learners themselves and interrelates with cognition and motivation. This chapter is a first attempt to integrate results and approaches from different fields. Our aim is to further develop formalizations of metacognition and GBL, and use them to specify, implement, and evaluate more effective metacognitive mechanisms. We believe that the next step for GBL is to move beyond specific designs for specific skills or domains and to identify which generic elements within the design of GBLEs can foster metacognitive knowledge and skills in learners.

chapter four

Design Framework

This chapter is based on the following journal paper:

Braad, E., Degens, N., Barendregt, W. & IJsselsteijn, W.A. (2021). Development of a design framework for metacognition in game-based learning. *Journal of Interactive Learning Research*, *32*(4), 295-323.

This chapter incorporates ideas from the following conference paper:

Braad, E., Degens, N., & IJsselsteijn, W. A. (2019). Towards a framework for metacognition in game-based learning. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th European Conference on Games Based Learning* (pp. 101–109). Sonning Common, United Kingdom: Academic Conferences and Publishing International.

Abstract and Research Flow

Learner metacognition can positively impact learning. However, little is known about how to effectively design GBLEs such that metacognition is promoted in learners. Previous research does not provide sufficiently structured and empirically verified insights for designers and researchers to make informed design decisions.

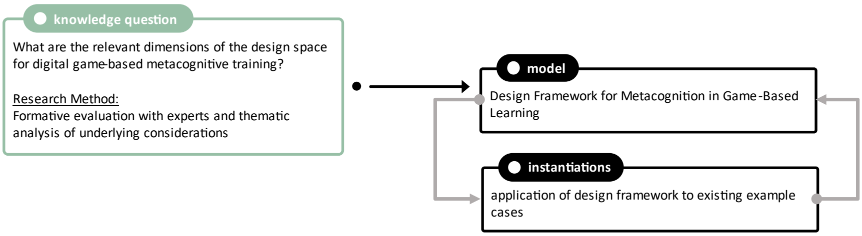


Figure 4.1: research flow for Chapter 4.

In this chapter, we describe the development of a design framework for metacognition in GBL. The framework is derived from existing literature and cases as identified in the previous chapter, and further elaborated through a formative expert evaluation. For the purpose of this evaluation, the framework is applied to existing example cases (see Figure 4.1).

For instruction, gameplay, and the integration of both, the resulting framework defines specific design dimensions that indicate the relevant areas in which informed design-decisions are likely to affect learners' metacognition. As such, this framework aids specification of designs, structured comparisons between different designs, and a focused research effort in identifying specific design guidelines for metacognition in GBL.

1. Introduction

The premise of GBL is that the unique aspects of games, such as challenge, fantasy, and interactive storytelling, have a positive impact on both motivation and learning (Garris et al., 2002; Plass et al., 2015). Over two decades of research have demonstrated that GBL can indeed motivate learners and help them to achieve specific learning outcomes (Wouters et al., 2013). Yet, the details of how to effectively combine game features with learning remain unclear (Graesser, 2017; Ke, 2016).

GBL takes place within a GBLE: the digital and interactive environment that contains both game elements and instructional elements (Plass et al., 2015; Vandercruysse & Elen, 2017). An important aspect to consider in the design of effective digital learning environments is metacognition (Azevedo et al., 2012; Lin, 2001): a learner's conscious understanding of how to use declarative, procedural, and conditional metacognitive knowledge about oneself, learning tasks, and strategies, to metacognitively plan, monitor, and evaluate learning (Pintrich, 2002; Schraw, 1998).

Previous research has recommended that the relationship between metacognition and the design of GBLEs should be researched to (1) encourage deep learning over shallow learning and so-called skill drills (Graesser, 2017); (2) encourage self-regulated learning (Nietfeld & Shores, 2011); (3) promote reflection on learning outcomes as well as the learning process (Ke, 2016; Paras & Bizzocchi, 2005; Vlachopoulos & Makri, 2017), and to (4) promote the use and development of metacognitive strategies while learning (Kim, Park, & Baek, 2009; Mayer, 2016). To ensure that metacognition is addressed effectively in GBLEs, it is important to understand how metacognition can successfully be encouraged and improved through the design of GBLEs. However, previous research focusing on metacognition in GBLEs has shown that it is difficult to abstract case-specific findings to more general guidelines for designing such environments (Braad, Degens, & IJsselsteijn, 2020).

The challenge in designing GBLEs is dealing with the degrees of freedom. As stated by Ke, Shute, Clark, and Erlebacher (2019) in their seminal work on the interdisciplinary design of GBLEs: "Game design is characterized by an open-ended or unspecified goal state and an extensive, indeterminate design problem space - in which the transition states (or paths) between the design input and output (or goal) states can be unlimited and their connections are unknown." To deal with this amount of freedom, it is important that a designer, or researcher, can 'navigate' the design problem space, to ensure that the design choices made contribute optimally to the design objectives.

When the expected design objectives include metacognition, however, it is hard to make well-informed design decisions by learning from previous design and research findings. First, previous research has found only a limited number of empirical studies of metacognitive mechanisms in GBLEs, and, moreover, these studies lack sufficient specificity and comparability to collectively inform future GBLE-designs (Braad et al., 2020). Ideally, such studies would have been repeated, connected, and refined to identify design guidelines; in reality however, most of the cases have never been touched again after the initial evaluations. Second, when designing for metacognitive outcomes, it is unclear which general aspects of GBLEs are even relevant to consider. In other words: it is unclear which design choices are likely to positively benefit learners, and hence warrant the effort of researching, testing, and implementing design guidelines to inform these choices.

In this work, a first step is made in dealing with the aforementioned challenge. In short, it is our goal to reduce the complexity of design by bringing structure to the possible design space one has to consider when addressing metacognition in GBLEs. By doing so, the potential impact of the choices made in that design space can be discussed. As a basis for this work, the conceptual model presented in Figure 4.2 was developed. In general, the underlying premise of GBL is that the interactions with the GBLEs lead to an impact on the learner (represented by 'a'). Previous research has focused on the typical GBL-outcomes of learning and motivation. However, additional research is needed into the role of more complex outcomes such as metacognition (represented by 'b'). While acknowledging the importance of motivational effects of GBL, in this chapter the focus is on cognitive and in particular metacognitive effects.

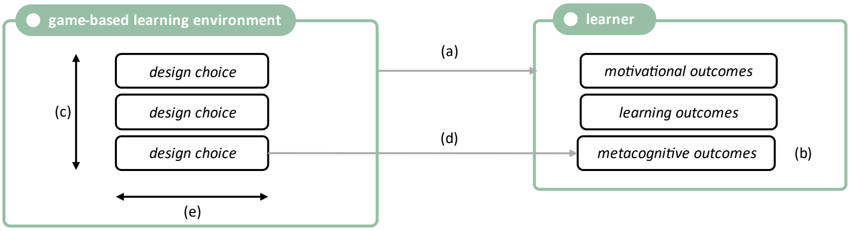


Figure 4.2: A conceptual model of designing game-based learning environments for impact on learners.

A GBLE is a designed artefact that is the result of multiple design decisions (represented by ‘c’), that were made either consciously or unconsciously. A formalized approach to designing GBLEs should thus consider how specific design choices affect specific learner outcomes (represented by ‘d’), and how such design choices are made deliberately and based on existing research. A design choice is also one particular sampling of the design space, and it follows that a design choice is part of some design dimension (represented by ‘e’) that describes a particular area of the design space. It is currently unclear, however, how this design space can be described, what these design dimensions should be, and what is known about the choices to be made.

The key question pursued in this chapter concerns the first two of these issues: how can the relevant design choices in designing GBLEs for metacognition be described? To advance insights in the design of digital GBLEs, the authors propose that a more detailed and structured approach towards the design of GBLEs must be taken. As such, in this chapter, the goal is to reduce the complexity of design by mapping out the design space of GBLEs for metacognition.

Ultimately, the objective is to aid both designers and researchers of GBLEs. For designers, the goal is to make it easier to focus on the relevant areas where informed decision-making is likely to affect the metacognitive outcomes the most. For researchers, the goal is to identify areas where more specific design guidelines that inform such design decisions for each dimension should be investigated. These objectives require that insights from existing literature, practical approaches studied in published experiments, and professional vocabulary of experts from different fields be combined. An iterative approach to constructing and evaluating such a framework is therefore adopted.

The chapter is structured as follows. First present, an analysis of the current literature and practical examples is presented, from which an initial set of design dimensions of GBLEs for metacognition is derived. Subsequently, a formative evaluation is discussed, in which experts evaluate these initial dimensions for three real-world cases of metacognition in GBL. The resulting design framework is presented. The implications that follow from both the resulting framework and the approach are discussed.

2. Design Dimensions for Metacognition in Game-Based Learning

As a first step, the aim is to identify and combine the theoretical and practical insights from existing literature that could inform the design of GBLEs for metacognition. In particular, the goal is to identify design dimensions that describe a particular and relevant area of choice-making for designers of such GBLEs. With such design dimensions, it should become easier to identify and describe the similarities and dissimilarities between designs – in turn making it easier to consider such design choices more consciously in future GBLE designs as well as GBLE research.

2.1 Derivation from Literature

This aim was addressed by analyzing literature on the design of metacognitive training. With the goal of formalizing the design space for GBLEs in mind, from existing literature, the dimensions that can be used to describe different approaches to implementing metacognitive instruction in digital tools were distilled. In line with previous literature (Garris et al., 2002; Vandercruysse & Elen, 2017), two perspectives on GBLE-design are employed: an instructional perspective that considers what aspects in the GBLE facilitate learning and a gameplay perspective that considers what aspects facilitate play.

For the instructional perspective, well-established work by Veenman, Van Hout-Wolters, and Afflerbach (2006), Schraw (1998), Pintrich (2002), Osman and Hannafin (1992) and Derry & Murphy (1986) presents ample general advice on the different considerations for designing metacognitive training. Four design dimensions for metacognitive instruction were identified (see Table 4.1).

For the game perspective, in contrast, there is only limited insight in how to address metacognition in the design of GBLEs. Work by Ke (2008a, 2008b, 2016), Greasser (2017), Nietfeld & Shores (2011) and Mayer (2016), however, addresses some of these considerations. For the game perspective, five design dimensions for gameplay were identified (see Table 4.2).

Table 4.1. Design dimensions for metacognitive instruction in GBLEs. For each dimension, its opposite ends, definition, and rationale for each, and references are shown.

(1) To what extent is metacognitive instruction embedded within domain-specific content?		
Opposites	**embedded**	**detached**
Definition	metacognitive instruction is part of the domain-specific learning content	metacognitive instruction is separated from domain-specific learning content
Rationale	makes it easier for learners to connect metacognitive knowledge and skills to concrete and ongoing learning	makes it easier for learners to isolate and transfer aspects of metacognition to different learning situations
References	Derry & Murphy (1986), Osman & Hannafin (1992), Hartman (2001a), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	
(2) To what extent is the metacognitive instruction direct about what a learner needs to do?		
Opposites	**direct**	**indirect**
Definition	metacognitive instruction is explicit about metacognition and aimed at increasing awareness and use of metacognition	metacognitive instruction is implicit about metacognition and aimed at improving use and effectiveness of metacognition
Rationale	helps learners to increase knowledge and awareness of metacognition	helps learners to produce metacognitive behaviors more often and more effectively
	addresses an availability deficiency by increasing knowledge	addresses a production deficiency by improving and practicing application
	may be best suitable for novice and young learners	may be best suitable for older and more advanced learners
References	Bannert & Mengelkamp (2013), Derry & Murphy (1986), Osman & Hannafin (1992), Ke (2016), Lin (2001), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	
(3) To what extent does metacognitive instruction guide students while learning?		
Opposites	**guided**	**unguided**
Definition	metacognitive instruction provides a learner with clear directions on what to do next	metacognitive instruction is available upon request from the learner
Rationale	makes learners perform effective metacognitive activities through guided practice	the ultimate goal is to become independent of external guidance
	may be used in the short term if gradually faded over time	allows learners to practice self-guidance without restriction
References	Azevedo et al. (2012), Bannert & Mengelkamp (2013), Derry & Murphy (1986), Graesser (2017), Osman & Hannafin (1992), Hartman (2001b), Lin (2001), Mayer (2016), Nietfeld & Shores (2011), Roll, Aleven, McLaren, & Koedinger (2007).	
(4) To what extent is metacognitive instruction integrated with the gameplay activities?		
Opposites	**extrinsically integrated**	**intrinsically integrated**
Definition	metacognitive instruction is situated outside of the gameplay activities	metacognitive instruction is situated within the gameplay activities
Rationale	reduces cognitive load and increases relevance of feedback to playing, learning, and metacognition	performance and motivation are positively impacted by meshing learning content with play
	may disrupt flow and be perceived as irrelevant	is unclear if this principle extends to integration of metacognitive instruction with gameplay
	may be unavoidable for complex learning content or content reflective in nature	
References	Graesser (2017), Habgood & Ainsworth (2011), Ke (2016), Nietfeld & Shores (2011), Plass et al. (2015).	

Table 4.2. Design dimensions for gameplay in GBLEs with metacognitive objectives (table continues on the following page).

(1) To what extent does the game involve social or individual interactions?		
Opposites	**individual**	**social**
Definition	a single player interacting with a GBLE	a range of players interacting within or outside of a GBLE
Rationale	allows learners to apply metacognition in their own way and at their own tempo	playing in groups is one of three most salient factors in effective GBL
	lack of social comparison promotes learners to experiment and risk failure	metacognition can be facilitated through social interactions within GBL
	individual debriefing of GBL is more effective than group-based debriefing	
References	Kim et al. (2009), Usart, Romero & Almirall (2011), Van der Meij, Leemkuil, & Li (2013), Wouters & Van Oostendorp (2013).	
(2) To what extent does the game involve competition or collaboration between agents?		
Opposites	**competitive**	**collaborative**
Definition	artificial conflict between agents	agents working together towards their goals
Rationale	produces motivation through challenge	collaboration in games can improve metacognition
	allows performance comparisons	collaboration fosters modelling metacognitive strategies from others
		collaboration fosters explication of otherwise covert metacognition
References	Ke (2008b, 2008a), Kim et al. (2009), Nietfeld & Shores (2011), Sanchez (2017), Schraw, Crippen, & Hartley (2006), Ter Vrugte et al. (2015), Usart et al. (2011), Vlachopoulos & Makri (2017), Zheng, Li, Zhang, & Sun (2019).	
(3) To what extent does the game involve deliberate or reactive responses from the player?		
Opposites	**deliberate**	**reactive**
Definition	players can deliberately consider and effectuate a choice	player must react quickly to changes in the game
Rationale	articulates thinking and allows learners to relate in-game choices to underlying principles	integrating learning content with action-based gameplay could hamper learning
References	Habgood & Ainsworth (2011), Martinez-Garza & Clark (2017), Mayer (2016).	

Table 4.2 (continued).

(4) To what extent does the game physically represent the target learning situation?		
Opposites	**physically fidelitous**	**physically fictitious**
Definition	the game environment looks, feels, smells, tastes, and/or altogether appears like the real world	the game environment deviates from representing reality
Rationale	strengthens the link between in-game and real-world concepts and situations, thereby improving transfer of learning	can emphasize relevant learning content by offering a more effective representation can improve motivation through fantasy and curiosity
References	Ke (2016), Mayer (2016), Rooney (2012).	
(5) To what extent does the game functionally represent the target learning situation?		
Opposites	**functionally fidelitous**	**functionally fictitious**
Definition	the game environment responds similar to interactions in the real world	the game environment deviates from simulating reality
Rationale	the game environment deviates from simulating reality	shifting rules can trigger metacognitive processing
References	Gallagher & Prestwich (2013), Ke (2016), Rooney (2012).	

2.2 Application in Practice

The question now remains whether these initial dimensions aid the description and comparison of GBLE-designs for metacognition in practice. Therefore, the dimensions were applied to a number of example cases. From a recent literature review of metacognition in GBL (Braad et al., 2020), five example cases, as dissimilar as possible in metacognitive objectives and mechanisms, were selected to represent a wide range of approaches to embedding metacognition in GLBEs.

For each example case, an in-depth learning task analysis was conducted, distinguishing between metacognitive activities, other instructional activities, and play activities. For each case, a labelled visual and structural analysis of the system elements and dynamics was constructed. Furthermore, any proposed metacognitive outcomes were indicated and linked to any active mechanisms implemented to address them.

With the results of this analysis, each of the dimensions was applied to each of the cases, and the results were visualized as a set of sliders with the position for that case indicated. Such design dimension dashboards show an *a priori* application of the design dimensions. Subsequently, it was confirmed that the dimensions could be applied to each case (i.e., the dimensions can be used to describe these widely differing cases) and that all salient aspects of each case were addressed (i.e., the dimensions cover the relevant design areas of these cases). The dashboards, along with a case description, are presented in the following sections.

Case #1: MMORPG

An MMORPG named Gersang (see Figure 4.3) is used to train economic concepts (Kim et al., 2009). The metacognitive objective is to increase knowledge and use of metacognitive strategies. Strategies are trained through direct instruction before play, can be applied as desired during play, and are self-explained after play. The game is set within a Korean medieval fantasy setting but contains a fidelitous economic simulation. The game is played online with other players and has a battle and an economic mode. Both competition and collaboration may occur and both reactive and deliberate gameplay is needed.

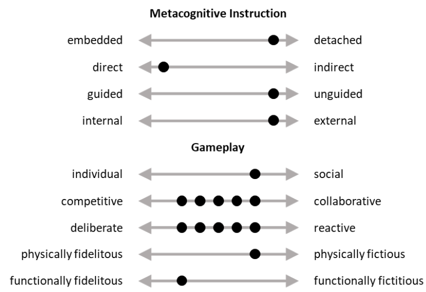


Figure 4.3: Design dimension dashboard for Case #1 (MMORPG).

Case #2: Construction Simulator

A 3D Construction Simulator (see Figure 4.4) is used to train construction project management (Castronovo, Van Meter, & Messner, 2018). The metacognitive objective is to encourage metacognitive monitoring and reflection, using cueing prompts and response prompts to self-explain scores. Learners can make choices at ease within a realistic 3D environment simulation. Prompts are presented in terms of and during domain-specific training but in between episodes of gameplay. Learners receive no further metacognitive support or feedback. Scores are awarded for achieving construction goals efficiently.

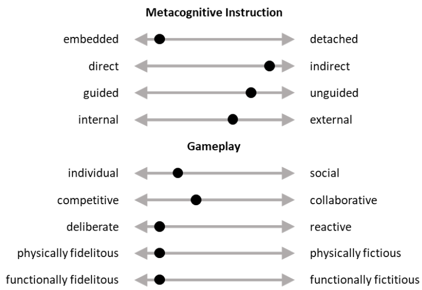


Figure 4.4: Design dimension dashboard for Case #2 (construction simulator).

Case #3: Circuit Game

A custom-made Circuit Game (see Figure 4.5) consists of compiling electrical circuits from electrical components to satisfy particular properties (Fiorella & Mayer, 2012). The metacognitive objectives are to encourage metacognitive monitoring and regulation through metacognitive cueing prompts and metacognitive scaffolding in the form of paper worksheets. The worksheets are in domain-specific wording and are continuously available. Prompts within the game encourage learners to self-explain current understanding but no further metacognitive support or feedback is provided. Players can make choices and selections at ease, receive feedback and scores. The game depicts the circuit in a standard abstract form of a circuit diagram. The game correctly simulates the effects of connecting the circuit as such.

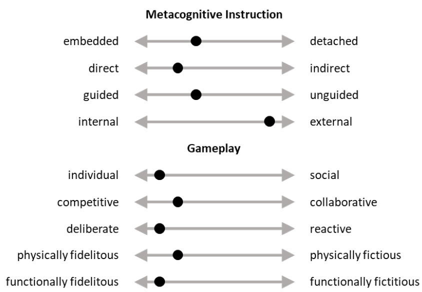


Figure 4.5: Design dimension dashboard for Case #3 (circuit game).

Case #4: Adventure Game

A story-driven adventure game (see Figure 4.6), set around the time and person of Galileo Galilei, is used to train physics (Verpoorten, Castaigne, Westera, & Specht, 2014). The metacognitive objective is to improve metacognitive knowledge in the form of accuracy of confidence in answer correctness. The metacognitive mechanisms are self-explication of confidence and metacognitive feedback on confidence. The game accurately simulates physics experiments which are not period correct. The confidence explication is presented as a sperate control on the physics experiment machinery. Feedback on confidence accuracy is provided separately from domain-specific feedback and as part of the narrative. To advance in the game, sufficient confidence must be gathered to convince Galilei to take you on as an apprentice.

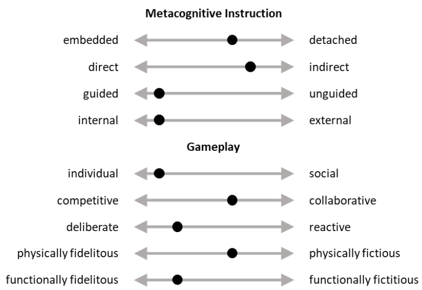


Figure 4.6: Design dimension dashboard for Case #4 (adventure game).

Case #5: Math Challenge

In this case (see Figure 4.7), problem-solving in mathematics is augmented with game challenges (Sun-Lin & Chiou, 2017). The metacognitive objective is to increase metacognitive awareness in algebra learning. The metacognitive mechanism is a self-explanation prompt, presented in terms of the problem, which asks to compare the learner's own solution against a correct or incorrect example. No other support or instructions during learning are provided. Specific challenges, points, and levels are awarded based on performance and progression.

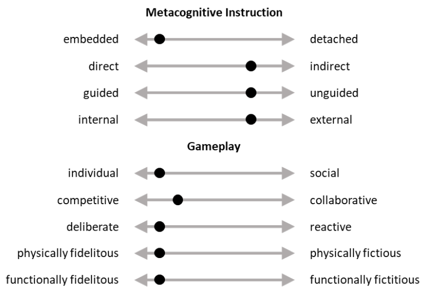


Figure 4.7: Design dimension dashboard for Case #5 (math challenge).

3. Formative Evaluation

With the set of dimensions that can, hypothetically, be used to both describe and differentiate metacognitive instruction in GBLEs, an important next step is to (i) identify which aspects are particularly relevant when considering metacognition in GBLE-design; and (ii) whether the proposed dimensions sufficiently represent these. A formative evaluation was conducted, in which a diverse range of experts was asked to discuss how the proposed dimensions apply to a number of real-world cases of metacognition in GBL. The following sections present the methodology, findings, and conclusions of this evaluation.

3.1 Methodology

Participants

From our network of professionals and researchers in relevant disciplines, such as game-based learning, instructional design, educational psychology, and metacognition in learning, 23 experts were invited. These experts were invited by mail, and reminded a few days later, resulting in 14 experts completing the evaluation.

Materials

To avoid asking the participants to read each of the corresponding papers, three of the five example cases were selected for the evaluation (i.e., the MMORPG, the circuit game, and the adventure game). A three-paragraph case description was constructed from the descriptions of instructional and gameplay elements from each original paper. The texts were edited to improve readability but kept as close as possible to the original. Each summary was augmented with screenshots of the respective GBLE (see Figure 4.8 for an impression and Appendix B for the game descriptions).

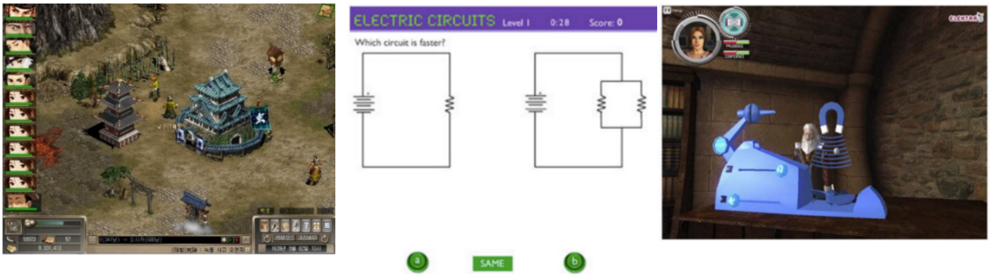


Figure 4.8: three different games employed in studying metacognition in game-based learning.

An online survey was constructed in which participants could, for each case description, rate and comment on each of the dimensions. For the dimensions of physical and functional fidelity, a brief definition and note emphasizing the distinction was provided. Ratings were requested to have participants consider and make a choice in terms of the dimensions, such that meaningful considerations would appear in the comments. Numerical ratings were requested for each dimension, on a scale from -3 through to +3 to indicate whether they found the instruction in the case description, for example, more direct (-3) or more indirect (+3). For each dimension, participants were asked to explain their choice.

Procedure

Each participant received a link to an online system guiding them through the materials. First, a brief introduction and explanation of the purpose of this study was given. Second, the participants were asked to process each of the three case descriptions. For each case, the system presented the case description, and asked participants to (a) rate and comment on the clarity of the description, (b) rate and comment on how the case relates to each of the dimensions, and (c) provide any additional comments. Participants were thus asked to motivate each of their ratings in text, to provide feedback on which of the included aspects were important, and to suggest aspects which were important but should yet be included. In this way, a discussion at the level of design dimensions was facilitated, while asking about concrete examples at the level of specific GBLEs.

Analysis

The comments were analyzed using *thematic analysis*: a structured method for identifying and interpreting meaning across the collected data (Braun & Clarke, 2012), that is suitable when experiential and explorative research questions are concerned, when responses to questions or prompts are to be analyzed, and when processing small datasets (Clarke & Braun, 2014). When applying thematic analysis, it is assumed that data analysis can never be objective, and that, rather, the choices that were made for the analysis should be made deliberately and communicated clearly. Here, a constructivist epistemology was adopted, as the analysis focused on identifying structural factors underlying the choices and motivations for choices of these experts. The data was analyzed by two researchers in an interactive discussion of analyzing, interpreting, coding, discussing, and re-coding, with the aim of identifying reoccurring themes. Since the data was collected by examining the dimensions in response to three case description, predominantly a deductive approach to collecting the comments was used. This deductive approach, combined with collecting data from knowledgeable field experts, allowed for strongly interpretative coding. Subsequently, an inductive approach was used to identify themes in the responses.

3.2 Results: Numerical

The numerical ratings provided by the experts were visually compared to the *a priori* ratings using a design dimension dashboard (see Figure 4.9). For most of the dimensions, the *a priori* rating is in the same direction and of comparable valence to the median expert rating, providing merit to the method. The largest differences occur within the dimensions *direct/indirect*, *guided/unguided*, and *extrinsic/intrinsic*.

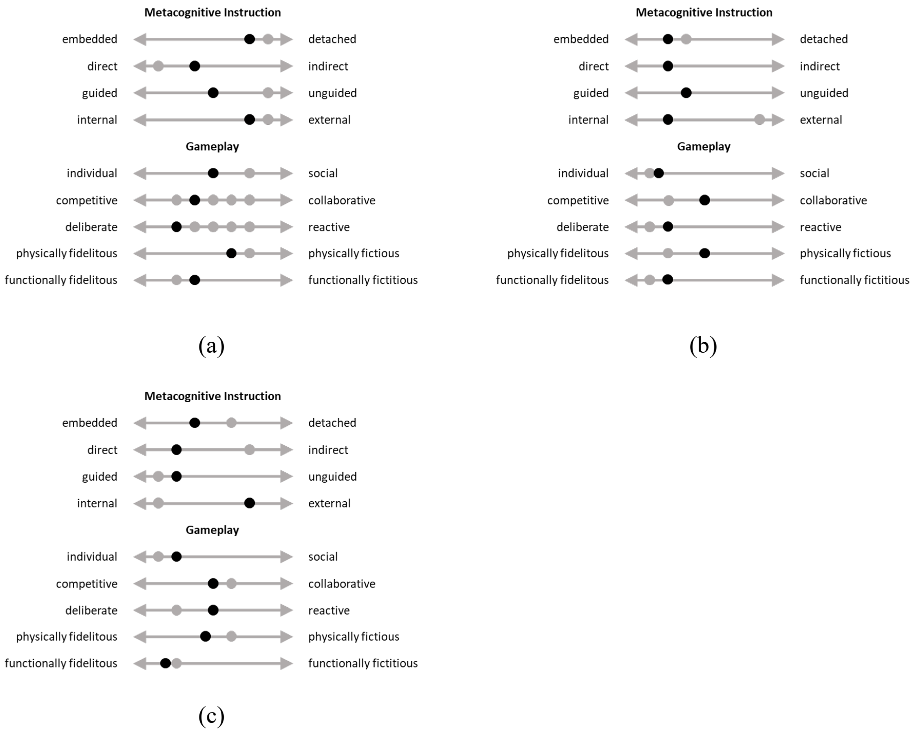


Figure 4.9: Design dimension dashboards comparing median expert ratings (black) to a priori ratings (grey) for each case: (a) MMORPG, (b) Circuit Game, and (c) Adventure Game.

3.3 Results: Contextual Information

The remaining results are separated into contextual information and themes. The contextual information, presented in this section, discusses the definitions of key terms with regards to the instructional and gameplay dimensions and, as such, they aid to demarcate and define the domain of discussion.

Dimensions for Metacognitive Instruction

A few respondents struggled to find metacognitive instruction altogether in some of the case descriptions. These respondents had adopted a narrow definition of instruction congruent with 'direct instruction' or 'explicit instruction' only. In a broader, and intended, definition, instruction encompasses 'indirect instruction' such as through feedback, prompts, or scaffolds.

Three distinct interpretations of the term 'direct' were identified among the responses: (a) learners having to do as the instruction says or being steered in a particular direction (i.e., directive; e.g., when a response is required to a prompt before one can proceed); (b) whether the instruction is simple, concrete, direct, and immediate (i.e., straightforward; e.g., immediate feedback on actions). The third, intended, interpretation was (c) direct as in explicit instruction: being concrete and upfront about what a learner needs to do. This approach to metacognitive instruction is also known from literature to be effective, as one respondent emphasized.

The distinction between metacognitive instruction being embedded in or detached from domain-specific content was widely supported. Additionally, it was suggested that metacognition can be general (i.e., in absence of domain-specific content, and aimed at affecting future learning situations).

Two distinct interpretations of the term 'guiding' were found. First, guiding can be interpreted, as intended, as supporting learners during playing and learning (e.g., through game-specific instructions, scaffolding, progress indicators, or scoreboards). Second, guiding can be interpreted as directing thoughts and actions of learners, (e.g., guiding learners into a specific direction through feedback).

Several specific remarks were made with respect to integrating metacognitive instruction extrinsically or intrinsically with the gameplay. Overall, metacognitive instruction was considered extrinsic to the gameplay if it is separated in time from gameplay or if it could be described separately from the gameplay. If links between metacognitive skills and the gameplay can be made, the balance shifts towards intrinsic. Metacognitive instruction was considered intrinsic to the gameplay if it is direct and domain-specific, tailored to this specific game, required to progress in the game, and when active elements in the gameplay encourage metacognition.

Dimensions for Gameplay

Respondents were divided over whether interaction with virtual agents can be interpreted as social gameplay. A narrow definition limits social play to interaction with other human players, whereas a broader interpretation includes NPCs agents to collaborate (e.g., work together with a master) or compete (e.g., overcome a master's stubbornness) with. Competition can also be internal to the player, rather than between (other) agents. Depending on internal or external motivation of the player, feedback as delivered by an in-game agent could also be perceived as competitive or collaborative. In absence of other agents that can influence players' actions there is no competition or collaboration between agents. In other words: individual play is neither competitive nor collaborative if the provided definition is used.

The proposed time-based interpretation of reactive versus deliberate play was supported: if less time is available to respond, the response is less deliberate and more reactive. An additional interpretation read: the more thought is required for a response, the more deliberate the gameplay is. A gameplay loop that supports thinking, then acting, and embeds this within a feedback loop to further encourage thinking before acting was suggested. A lack of using insight to look forward makes gameplay reactive – which was suggested as a hook for metacognition to prevent this from happening.

For one respondent, the terms fictitious and fidelitous were not clear enough to be applied. The provided definition of physical fidelity ("whether the game appears like the concepts-to-be-learned in the real world") was found too broad in that it does not make concrete what it applies to: the game as a whole, the visual aspects of the game, or something else. One respondent provided a narrower definition pertaining to the setting of the game only. Various comments indicated that respondents did not distinguish between physical or functional fidelity: some of the responses were literally the same (e.g., that the context seems fictitious) or reversed (e.g., remarking under functional fidelity that the electrical circuits appear as a in reality). How the game, the gameplay, and the interactions represent the real world is important for how fidelitous the game is to the target learning situation. This holds for the domain learning content (e.g., whether the game represents electrical circuitry, or diagrams thereof) as for metacognition (e.g., whether confidence is represented accurately).

3.4 Results: Themes

In this section, the themes uncovered through thematic analysis are presented. Six themes were identified, where each theme represents respondents' views related to the same area of design of GBLEs for metacognition.

Theme #1: Combining Metacognitive Instruction with Learning Content and Gameplay

A main theme that re-occurred throughout respondent comments was the complexity of the relationships between (a) metacognitive instruction, (b) learning content, and (c) gameplay.

The relationship between metacognitive instruction and learning content (a-b) was included as an initial dimension and was confirmed by respondents. It was suggested that the reverse, whether any domain-specific learning content is present in the metacognitive instruction, is also relevant.

The relationship between learning and gameplay (b-c) was often mentioned and related to the design principle of striving to maximize integration between learning content and gameplay. However, as this principle of intrinsic integration does not necessarily apply to promoting metacognition, this was not included among the initial dimensions. Nonetheless, apparently it was hard for respondents to distinguish metacognitive from non-metacognitive content, which further underlines the need for more clarity.

The relationship of metacognitive instruction to gameplay (a-c) was included as an initial dimension extrinsic/intrinsic. The gameplay dimensions were intended to further specify this relation, however, respondents discussed many of these aspects early on when asking themselves whether the gameplay lends itself for metacognition (see deliberate/reactive), whether there are any mechanisms in the game that contribute to metacognition (see guided/unguided), and whether the amount of fantasy precludes metacognition (see fidelitous/fictitious).

Theme #2: Considering the Game within its Layered Context

A related theme is how metacognitive instruction is related to GBL. An initial dimension of extrinsic/intrinsic integration was included, however, respondents considered different ways of integrating metacognitive instruction. Respondents distinguished between metacognitive instruction (a) within the game, (b) within the digital system in which the game is presented, but outside of the game itself, and (c) within the real-world context of learning. For example, a metacognitive prompt could be disguised as part of the gameplay or, alternatively, be presented digitally after a gameplay episode or physically within a classroom. Furthermore, (d) the target learning situation, in which the concepts-to-be-learned are to be applied, needs to be considered if transfer of learning or metacognition is expected. Altogether, these different layers help to take into account the structural relationship between gameplay activities and learning activities.

Theme #3: Considering the Temporal Aspects of Metacognitive Instruction and Gameplay

Various comments referred to how metacognition, learning, and playing occur over time. For example, there can be time between (pre-play) instruction and (during play) application of metacognitive instructions. This would require a learner to near-transfer the instructions to play. In contrast, (metacognitive) feedback can be immediate within the gameplay. One respondent specifically suggested being more specific about the temporal aspects, for example by indicating the consecutive order of tasks, levels, or episodes of GBL.

Responses may also develop learner insight over time. For example, simply trying out different solutions in a reactive way may lead to more deliberate responses later on, provided that trial-and-error is followed by more informed strategy adaptations. Such adaptations, to inform future responses, are interpreted as reactive by some respondents. According to respondents, any metacognitive instruction needs to adapt to such changes in the player in order to provide sufficient but not too much guidance.

Theme #4: Taking Player Autonomy into Account

Social or individual play depends, according to the respondents, not only on the gameplay but also on how one plays. For example, an individual game can be deployed in a social way (e.g., when playing in dyads in a classroom), and a player that focuses on the goals (i.e., what is best rewarded within the game) will seek out competition or collaboration as needed. Even with the same game, players may respond differently or have a different experience. In some games, both reactive and deliberate responses may be needed to progress, while in other games the agency a player experiences may be so limited that it cannot be considered deliberate. Altogether, how much autonomy the player has in responding to the game needs to be taken into account.

A related observation was that any guidance needs to be connected to learners, and the type of guidance matters in how well metacognition is supported. Aspects that qualify guidance are how overt, present, and explicit guidance is with respect to metacognition.

Theme #5: Level of Analysis

To some extent, the initial dimensions were connected to specific game mechanics by the respondents. For example, multiplayer real-time battles can be described as social, reactive, and competitive play. Similarly, a leaderboard can be characterized as social and competitive. However, as respondents remarked, the analysis of design cannot always be at the level of specific game mechanics. For example, a typical MMORPG will contain individual and social types of play. An analysis per gameplay mode, as was suggested, does not fully resolve the issue. For example, players can collaborate to compete with another group of players, and players can combat each other but collaborate with other agents. Some mechanics are even inherently multi-faceted: trading can involve elements of competition as well as collaboration.

Theme #6: Limitations to Integrating Metacognition with Gameplay

Some respondents questioned whether metacognitive instruction can be made fun enough to be a proper part of the gameplay. Even if metacognitive instruction were integrated to become a part of the gameplay this may adversely affect enjoyment. A similar mismatch could occur if metacognitive instruction does not clearly support the learning content, or if the amount of fiction precludes metacognition. Perhaps fully integrating metacognition in gameplay may inherently not be possible due to its introspective nature and, perhaps, it may not be altogether desirable.

In terms of fidelity, one respondent wittingly remarked that in the real world there will be relatively few metacognitive prompts. Joking aside, indeed, certain elements that aid learning are not there in the real-world – such as prompts – and make such approaches inherently non-fidelitous to some extent. Also, as gameplay is experienced through a device mediating interaction, it does not involve the real-world experience and interactions. Finally, gameplay is bounded in time and possibilities and hence cannot be fully fidelitous.

Respondents emphasized the importance of a link between the metacognitive approach and real-world learning, with one respondent stipulating that metacognition is not fully independent of either the learning content or the context of the game.

4. Design Framework for Metacognition in GBL

The goal of this work is to reduce the complexity of design when designing GBLEs for metacognition. Based on the theoretical background and the results of formative evaluation, the adjustments leading to an initial design framework for metacognition in GBL are now discussed.

4.1 Adjustments

The results show that key concepts must be clearly defined. The results also show that a dimensional perspective, alone, cannot convey the complexities of design. Often, interrelations between such dimensions play a role. For example, the integration of metacognition into gameplay could not be seen apart from embedding metacognitive instruction in domain content or from integrating domain content into gameplay itself. Furthermore, the results show that the dimensions cannot be completely separated from the intended outcomes. For example, metacognitive instruction aimed at general, rather than at domain-specific, metacognitive outcomes is in itself domain-general instruction. Altogether, this led us to conclude that the design space of GBLE for metacognition is better described as a framework that combines key concepts, design dimensions, relations between design dimensions, and relations between design dimensions and real-world outcomes.

While the evaluation confirmed that an important part of metacognition in GBL revolves around integration of metacognitive instruction, it was not sufficiently clear how the dimensions helped to describe this relationship. To provide more clarity, the relationships between metacognitive instruction, domain-specific learning content, and gameplay is now more clearly represented by explicitly describing the dimensions as three different but related views on integration. The relationship between learning content and gameplay is now included.

The dimension *extrinsic/intrinsic* integration is now more clearly specified: integration can occur at different layers (i.e., gameplay, GBLE, digital system, real-world context) and at different times of interactive learning (i.e., before, during, after).

The dimension *domain-general/domain-specific* metacognitive instruction is introduced to reflect the additional option of domain-general metacognitive training. This dimension is linked to metacognitive and domain-specific outcomes. To avoid confusion, the dimension of *direct/indirect* instruction is renamed to *explicit/implicit*.

The dimension *guided/unguided* instruction caused some confusion. Upon further reflection, this dimension also coincided too much with simply the presence or absence of any metacognitive support. More relevant, however, is to what extent the system or the learner is the active agent in metacognitive learning and how autonomously the learner can operate. Therefore, this dimension is replaced by a new dimension *system-controlled/learner-controlled* instruction. This dimension can also further characterize the extent to which instruction is static or adaptive.

The two fidelity dimensions are now combined as *fidelitous/fictitious*: the distinction between physical and functional fidelity proved more confusing than helpful in describing GBLE designs.

An updated overview of the dimensions of the framework is provided in Appendix C.

4.2 Overview of the Framework

The design framework for metacognition in GBL relates learner outcomes of GBL to gameplay, learning content, and metacognitive instruction within the GBLE (see Figure 4.10).

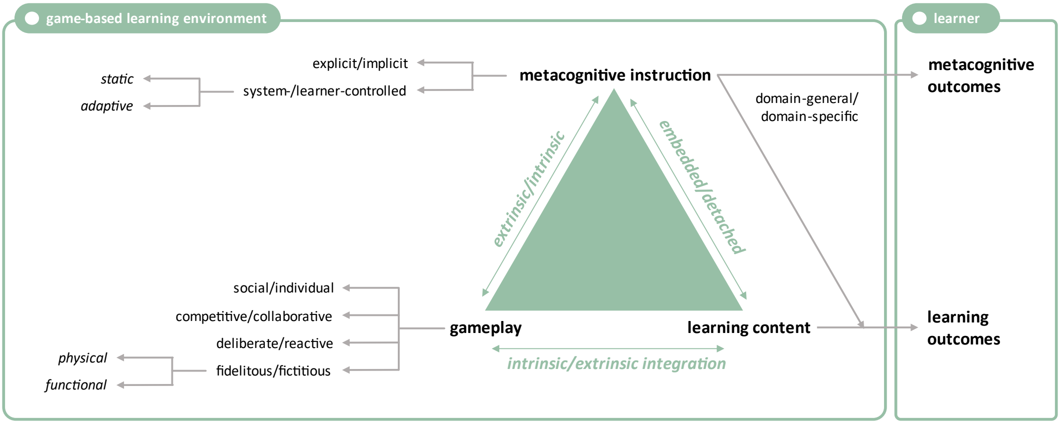


Figure 4.10: Design framework for metacognition in GBL.

Concepts and Objectives

The goal of GBL is to help a learner to achieve learning outcomes in the real world (right hand side of figure), for which a GBLE is designed (left hand side of figure). The design of a GBLE combines *gameplay*, domain-specific *learning content*, and *metacognitive instruction* (triangle). Here, metacognitive instruction is be defined as any mechanisms implemented within the GBLE with the goal of encouraging metacognition in learners, whereas metacognitive objectives are defined as the desired metacognitive effects of the GBLE on the learner. Metacognitive objectives can relate to the domain-specific learning outcomes or stand on their own as separate outcomes.

The design space of GBLEs for metacognition can be described as three distinct areas: integration, metacognitive instruction, and gameplay, with each characterized by more specific design dimensions.

Dimensions for Integration

Metacognitive instruction can be *extrinsically integrated* or *intrinsically integrated* with the gameplay. This relationship is further characterized by structural aspects (i.e., within the game, the GBLE, the digital system, the real-world context) and temporal aspects (i.e., before, during, after learning). Both extrinsic and intrinsic integration of metacognitive instruction may be effective, although fully integrating metacognition with gameplay may not always be possible or desirable. Metacognitive instruction can range from *embedded in* to *detached from* domain-specific learning content. For domain-specific metacognitive goals, metacognitive instruction is best embedded in domain-specific learning content.

Dimensions for Metacognitive Instruction

Metacognitive instruction can range from *domain-specific* to *domain-general* (Derry & Murphy, 1986; Osman & Hannafin, 1992; Veenman et al., 2006). Domain-general metacognitive instruction aims to transfer to future learning situations, whereas domain-specific metacognitive instruction usually aims to aid the attainment of domain-specific learning objectives.

Metacognitive instruction can range from *explicit* to *implicit*. While novice learners benefit from explicit instruction (e.g., direct instruction on metacognitive strategies), more advanced learners may benefit from implicit instruction (e.g., feedback and cues regarding strategy use).

Metacognitive instruction can range from *system-controlled* to *learner-controlled*. While predominantly system-controlled instruction may initially force learners to engage in metacognitive processing, increased learner control is eventually required to practice with self-initiating and automating metacognition. As the need for explicit or implicit instruction, as well as for system- or learner-controlled instruction, varies with the level of learner experience, GBLEs may need to adapt metacognitive instruction to individual learners (Azevedo et al., 2012; Nietfeld & Shores, 2011).

Dimensions for Gameplay

The game design, and in particular the gameplay mechanics and the setting, needs to accommodate metacognition: a game that does not allow for, support, encourage, or require metacognition will not be at the core of a successful GBLE for metacognition. Gameplay can range from *social* to *individual*, and from *competitive* to *collaborative*. This depends, in part, on how the game is employed within its context and how players act and interact within the GBLE.

Gameplay can range from *deliberate* to *reactive*. Here, sufficient time for decision-making is important for metacognition, but the amount of thought required can progress from little (e.g., trial-and-error) towards strategic (e.g., through metacognitive feedback).

Gameplay can range from *fidelitous* to *fictitious*. Here, fidelity is subdivided into the game's appearance (i.e., physical fidelity), and the game's dynamic interaction (i.e., functional fidelity). Fidelity to the target situation also pertains to metacognition: the metacognitive content must be applicable to the learning task or domain of learning at hand.

5. Discussion

In this chapter, the development of a framework to support metacognition in the design of GBLEs was discussed. Theoretical insights from literature were combined with practical insights from concrete cases, and elaborated the findings through a formative expert evaluation. The resulting framework aims to reduce design complexity by indicating which design dimensions are relevant to consider when addressing metacognition within GBLEs. The framework, along with the design dimension dashboard diagrams, further aids comparing designs, as relevant differences and similarities can be more easily identified along the provided dimensions. If current and novel approaches can be described in such underlying and commonly shared terms, this area of research can advance towards making links between different approaches and their effects on learning, motivation, and metacognition.

There are inherent limitations to the adopted approach. For example, the results from the formative evaluation did not completely match our expectations: the discussion of the gameplay dimensions was less focused on metacognition than anticipated.

While it is promising to see some confirmation that this important consideration is now becoming a commonly held design guideline, it should not prevent or preclude other important considerations.

Another limitation is that our approach of using existing cases to perform a formative evaluation bears in it the risk of these cases comprising an ill-formed representation. While real-world cases were selected and presented carefully, perhaps more different cases could have probed more variation in responses. The validity of working with real-world cases, and deriving these from the original publications as included in an up-to-date review of the literature, however, should sufficiently address the presented risks.

The formative evaluation uncovered that a lack of shared understanding and terminology is still a key issue in GBLE-design: even among experts, there is disagreement over how different aspects of games and learning are discussed. Based on the evaluation results, some of the terms used during the evaluation, were reverted to an earlier version (see Braad, Degens, & IJsselsteijn, 2019b). As words only go so far in communicating the design of a dynamic interactive system, and with this issue present in almost any paper on GBL, if anything, this underlines our premise that a more formal approach to designing and discussing GBLEs is of added value (see also Nadolny et al., 2020).

A key benefit of the framework is that it can be used to inform design (which choices to make) as well as research (which areas to research). With a design framework in place, a logical next step is to identify, investigate, and verify specific design guidelines for metacognition in GBLEs. Even though motivation has salient interrelations with metacognition, it did not fit within the focus of our work. This demonstrates that, while our focus is on metacognition, our contribution and approach could extend beyond. The authors encourage others to adopt a degree of formalism and support well-informed decision making and clear communication about GBLE designs.

chapter five

Improving Metacognition with a Digital Tool

This chapter is based on the following journal paper:

Braad, E., Degens, N., Barendregt, W. & IJsselsteijn, W.A. (2022). Improving metacognition through self-explication in a digital self-regulated learning tool. *Educational Technology Research and Development*, 70, 2063-2090.

Abstract and Research Flow

Digital support during self-regulated learning can improve metacognitive knowledge and skills in learners. Previous research has predominantly focused on embedding metacognitive support in domain-specific content.

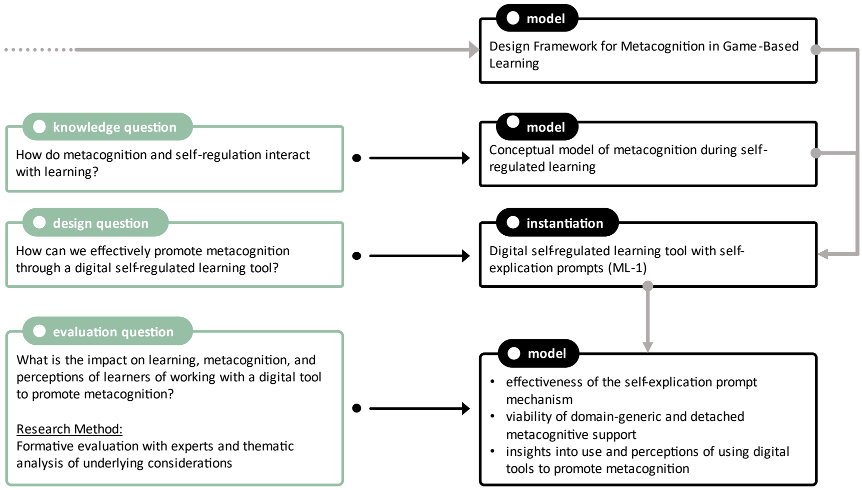


Figure 5.1: research flow for Chapter 5.

In this chapter, we examine a detached approach where digital metacognitive support is offered via a digital tool in parallel to ongoing domain-specific training (see Figure 5.1). This detached approach is well-suited for game-based learning, but is here first tested for effectiveness without any game elements.

The design of this tool is derived from the instructional dimensions of the design framework introduced in the previous chapter; however this derivation is not made explicitly within the chapter (alternatively, this explication is provided in Appendix D). A specific conceptual model of metacognition during self-regulated learning is introduced to underpin the design of the tool. The primary support mechanism is self-explication, where learners are prompted to make, otherwise implicit, metacognition concrete.

In a controlled pre-test/post-test quasi-experiment, we compared domain-specific and domain-general support and assessed the effects, use, and learners' perceptions of the tool. The results showed that self-explication is an effective mechanism to support and improve metacognition during self-regulated learning. Furthermore, the results confirm the effectiveness of offering detached metacognitive support. While only domain-specific metacognitive support was found to be effective, quantitative and qualitative analysis warrant further research into domain-general and detached metacognitive support.

1. Introduction

Self-Regulated Learning (SRL) characterizes learners as active participants in their own learning process who study how they learn and how learning helps them to achieve their goals (Winne, 2010; Zimmerman, 1989). For a learner to successfully self-regulate their learning, sufficient cognitive ability and motivation must be met with sufficient *metacognition*: the knowledge of one's own cognitive processes and products, and the skills to regulate cognitive aspects of the learning process (Flavell, 1979; Schraw, Crippen, & Hartley, 2006). In this study we examine whether metacognition can be improved through self-explication of metacognitive processes in a digital SRL-tool.

In the past two decades, researchers have studied digital tools for supporting metacognition and SRL (Azevedo, 2005b; Hadwin & Winne, 2001; Winters, Greene, & Costich, 2008), with the majority of research focusing on *embedding* metacognitive support within the content of *domain-specific* digital learning environments (Azevedo et al., 2012; Broadbent, Panadero, Lodge, & De Barba, 2020). For example, a digital learning environment designed to offer instruction and practice for mathematical problems may be augmented with instructional support, promoting help-seeking and self-monitoring (e.g., Arroyo et al., 2014). Alternatively, a digital tool could offer such support independently of any domain-specific content. Such *domain-general* metacognitive support could be offered *detached* from, but in parallel to, ongoing learning. Potential benefits of domain-general support are that learners can identify and isolate metacognitive knowledge and skills that apply across different learning situations and altogether have more opportunities to practice and improve their learning (Derry & Murphy, 1986; Osman & Hannafin, 1992). While ample research addresses digital metacognitive support in a domain-specific and embedded way (Bannert & Mengelkamp, 2013; Schwonke et al., 2013), current research lacks insights into the design, use, and effects of detached and domain-general digital metacognitive support.

In this chapter, we study a detached digital SRL-tool supporting domain-general metacognition through *self-explication*: prompting learners to make otherwise implicit metacognition concrete. We focus on the improvement of metacognition of learners in higher education, who have some experience in learning but tend to produce ineffective learning behaviors. First, we introduce the key concepts of SRL, metacognition, and digital instructional support. Second, we present the design of the tool and the domain-specific and domain-general metacognitive support implemented to help learners. Third, we discuss the evaluation of the tool in an in-vivo quasi-experiment aiming to assess effects, use, and learners' perceptions of the tool. The chapter concludes with discussing the results and formulating implications for design as well as future research.

2. Background

2.1 Self-Regulated Learning and Metacognition

SRL encompasses cognitive, metacognitive, behavioral, and affective aspects of learning and has become an important conceptual framework for educational research (Panadero, 2017; Winne & Hadwin, 1998; Zimmerman, 1989). While various models co-exist in literature, SRL is generally described as learner behaviors during three cyclic phases: (1) a *preparatory* phase (task analysis, goal-setting, and strategic planning), (2) a *performance* phase (enacting strategies and tactics, monitoring performance and progress, and adapting goals, plans and strategies), and (3) an *appraisal* phase (reflection, adaptations for future performance) (Panadero, 2017; Puustinen & Pulkkinen, 2001).

Different research perspectives on SRL have identified a large number of factors involved. A *social* perspective of SRL relates learning to influence *of* and influence *on* personal, behavioral, and environmental factors affecting learning (Zimmerman, 1989). Correspondingly, learners employ SRL-strategies such as self-evaluation, seeking social assistance, or environmental structuring. An *affective* perspective of SRL relates learning to emotional and motivational processes that occur during learning (Boekaerts, 1997; Boekaerts & Cascallar, 2006). A *metacognitive* perspective of SRL emphasizes the cognitive and metacognitive processes involved in learning (Azevedo, Cromley, Winters, Moos, & Greene, 2006; Efklides, 2014; Winne, 2010; Winne & Hadwin, 1998).

In this chapter we focus on this metacognitive perspective and how students in higher education could benefit from metacognition in learning. First, learners use *metacognitive skills* to estimate their ability, make predictions about their performance, and accordingly set realistic goals, make strategic plans, and monitor and regulate their learning effort (Pintrich, 2002; Schraw & Moshman, 1995; Veenman & Spaans, 2005). Second, learners use *metacognitive knowledge* of what strategies are available, how to implement these strategies, and under which conditions these strategies are effective (Ertmer & Newby, 1996; Pintrich, 2002; Schraw, 1998; Schraw & Moshman, 1995). Third, learners have beliefs about their learning and such *metacognitive theories* are used to steer cognition through metacognitive processes (Bjork et al., 2013; Dweck, 1986; Schraw & Moshman, 1995; Winne & Nesbit, 2009).

Consider, for example, a learner who thinks that learning will be more effective when more concerted effort is invested (metacognitive theory), who may know that, for them, part of the effort should involve discussion of the materials with peers (metacognitive knowledge), and may correspondingly plan and schedule such sessions in advance (metacognitive skills). However, metacognitive theories are not necessarily correct and metacognitive knowledge is not necessarily optimal. Consider, alternatively, a learner who believes that learning is mostly about repeating the material (metacognitive theory), may only know cramming for the test as a strategy (metacognitive knowledge), and may find that, upon monitoring progress, learning does not proceed as well as hoped (metacognitive skills). Metacognitive support of SRL can thus seek to (i) encourage learners to apply, evaluate, and improve their metacognitive theories in response to evidence gathered during learning, (ii) expand and improve metacognitive knowledge of learners, and (iii) improve the occurrence and quality of metacognitive skills, or any combination thereof.

Students entering higher education have previous experience with learning from primary and primarily secondary education. However, they need to make a transition from one educational phase to the next, as they are increasingly expected to self-regulate learning and take individual responsibility for and control of learning, in a pursuit of more complex learning outcomes (Kane, Lear, & Dube, 2014). At the same time, development of metacognition is known to continue well into adolescence and young adulthood (Schneider, 2008). Students who make active use of metacognition perform better than students who do not, and are more aware of how metacognitive knowledge can be used to improve cognitive processing of learning material (Meijer et al., 2013; Romainville, 1994; Veenman et al., 2006). An effective way of improving learning for such students is to improve their metacognitive awareness by fostering reflection on their own approach to learning (Brown & Palinscar, 1989; Meijer et al., 2013; Romainville, 1994).

2.2 Metacognitive Support

SRL and metacognition can be improved through instructional support (Callender, Franco-Watkins, & Roberts, 2016; McCormick, Dimmitt, & Sullivan, 2013). Three common and effective types of metacognitive support are *direct instruction* (Kim et al., 2009; Schraw, 1998; Zepeda et al., 2015), *metacognitive scaffolding* (Arroyo et al., 2014; Azevedo & Jacobson, 2008), and *metacognitive prompting* (Bannert & Mengelkamp, 2013; Hoffman & Spatariu, 2008). Direct instruction can, for example, be used to explain what metacognitive strategies are, and how and when to use them effectively (e.g., Jansen, Leeuwen, Janssen, Conijn, & Kester, 2020). Metacognitive scaffolding can support metacognitive processes, for example by letting a virtual character announce and explain at each step of a learning task (e.g., Molenaar, Boxtel, & Sleegers, 2011). Metacognitive prompts are typically used (i) as a cue to remind a learner of and focus attention on metacognitive processing (Fiorella & Mayer, 2012; Merriënboer & Bruin, 2019), (ii) as a request to self-explain current understanding with the aim of triggering metacognitive monitoring and regulation (e.g., McNamara, 2009; Yeh, Chen, Hung, & Hwang, 2010), or (iii) as a combination thereof (e.g., Bannert & Reimann, 2012). However, previous research has not investigated the use of prompts primarily to enable learners to self-explicate metacognitive processing with the purpose of examining and improving metacognition. Metacognitive theories can be improved when learners apply them to learning, evaluate them for merit, and adjust them in response to evidence (Bjork et al., 2013; Schraw & Moshman, 1995). Self-explication, when prompted, allows learners to examine such otherwise implicit metacognitive theories. As the goal is for learners to, eventually, self-initiate regulation in absence of any support, the design of such tools must provide for sufficient support while not precluding opportunities for learners to self-regulate (Arroyo et al., 2014; Broadbent et al., 2020; Griffin et al., 2013; Hattie et al., 1996). Prompting learners to explicate, examine, and improve their metacognitive processes during learning could potentially support SRL while allowing for sufficient learner control.

Metacognitive support can be delivered through digital tools (Altıok, Başer, & Yükseltürk, 2019; Bannert & Mengelkamp, 2013; Connor et al., 2019), which generally fall into one of two categories: *embedded instruction* within domain-specific digital learning environments and *detached instruction* provided outside of, and prior to or in parallel to, ongoing domain-specific training (Broadbent et al., 2020; Osman & Hannafin, 1992). Embedded instruction typically (i) augments domain-specific content with cognitive tools aiding information processing (Bannert, Hildebrand, & Mengelkamp, 2009; Winne, 2010; Winne et al., 2006), (ii) uses data gathered from learning to provide meaningful feedback and support to learners to help them overcome particular challenges (Winne et al., 2006), and (iii) makes use of interactive and multimedia environments to situate SRL-support (McQuiggan & Hoffmann, 2008; Sabourin, Shores, Mott, & Lester, 2013). Detached instruction, in contrast, makes few assumptions about the content of learning, and instead focuses on supporting metacognition during different parts of the learning process (Broadbent et al., 2020; Derry & Murphy, 1986; Osman & Hannafin, 1992). An example of detached instruction is offering video-based training of SRL through a dedicated digital learning environment (Jansen et al., 2020).

Metacognition is in part *domain-specific*, with limited transfer to other learning situations, and in part *domain-general* and transferrable between different domains (McCormick et al., 2013; Schraw, 1998; Veenman et al., 2006; Wang, 2015). Domain-specific metacognitive knowledge (e.g., knowing the steps to solve an equation) and skills (e.g., checking if a solution is plausible) are embedded in ongoing learning, making acquisition more straightforward (Bannert & Mengelkamp, 2013; Lin, 2001; Veenman et al., 2006). Domain-general metacognitive knowledge (e.g., knowing oneself as a learner, knowing general learning strategies) and skills (e.g., planning, monitoring, and regulating learning) can be applied effectively across a wide range of learning situations (Broadbent et al., 2020; Osman & Hannafin, 1992; Wang, 2015). Domain-general metacognitive instruction is agnostic to the content of learning and thus can be offered embedded in or detached from domain-specific instruction. Thus, while domain-specific metacognitive support is easier for students to connect to their learning, domain-general support can be applied across many different settings of learning. From a design perspective, the challenge is to make metacognitive support generic enough to replicate across different domains while remaining specific enough for students to apply. Here, detached instruction allows learners to more easily identify potential transfer to future learning situations (Derry & Murphy, 1986; Osman & Hannafin, 1992; Veenman et al., 2006).

2.3 Outline

Previous research has focused predominantly on embedded and domain-specific digital metacognitive-support for specific elements of SRL (Azevedo, 2020; Bannert & Mengelkamp, 2013; Merriënboer & Bruin, 2019; Veenman et al., 2006). However, little is known about domain-general and detached digital metacognitive support across all phases of SRL, or about self-explicating otherwise implicit metacognitive processes. The present study investigates the design of detached digital metacognitive support for students in higher education. The three key research questions are:

- Can metacognition of learners be improved through self-explication within a digital SRL-tool that is detached from domain-specific learning?
- Can detached metacognitive support be domain-general or must there be a connection with domain-specific learning?
- How do learners make use of, sustain use of, and perceive the use of such a detached digital SRL-tool?

The remainder of this chapter discusses a digital tool that supports self-explication. After the design of the tool is presented, an evaluation of how the tool affects learners, how learners use the tool, and how learners perceive using the tool is discussed. The results and corresponding implications for the design and research of digital metacognitive support are discussed.

3. Design of a Digital Self-Explication Tool

3.1 Concept

The design goal for the tool was to improve metacognition by encouraging learners to make connections between (i) their knowledge, beliefs, and assumptions about learning, (ii) an ongoing and concrete learning process, and (iii) improvements made to this learning process for current as well as future learning tasks.

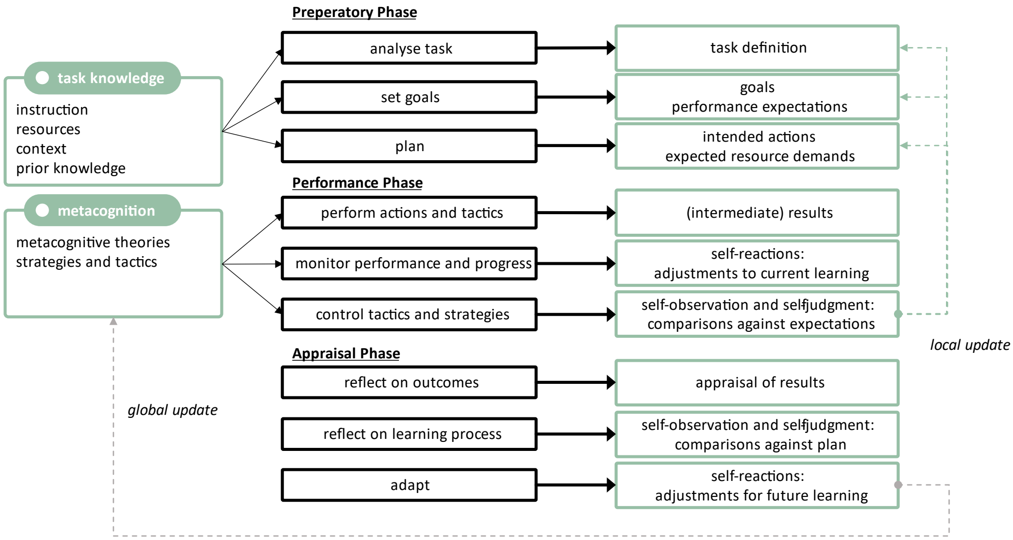


Figure 5.2: Conceptual model of metacognition during self-regulated learning.

The following conceptual model of metacognition during SRL was created to facilitate the design (see Figure 5.2). The conceptual model was derived from the COPES-model (Winne & Hadwin, 1998), is supported by ample empirical evidence and is widely used in studying computer-supported learning (Greene & Azevedo, 2007; Panadero, 2017; Winne & Nesbit, 2009).

Task-relevant learner knowledge is represented as either task knowledge or metacognition (metacognitive theories, strategies, and tactics) (cf. Ertmer & Newby, 1996; Schraw & Moshman, 1995; Winne & Hadwin, 1998). The model combines the preparatory, performance, and appraisal phases of SRL with five facets of learning: (i) the conditions for learning (e.g., task conditions and cognitive conditions), (ii) the operations involved in learning (e.g., tactics and strategies), (iii) the (meta)cognitive products that are the result of learning (e.g., task definition, plan), (iv) the evaluations that are made of learning (e.g., judgment of learning), and the standards that learning are held to (e.g., expectations based on past performance).

During each phase, it is indicated how (meta)cognitive activities are informed by task-relevant knowledge, and how each activity is assumed to result in (meta)cognitive products, through self-observation, self-judgment, and self-reaction (Winne & Hadwin, 1998; Zimmerman, 1989). As such, this conceptual model defines two specific ways in which learners adapt their learning in response to observations and judgments. First, metacognitive monitoring and control lead to adaptations of the current task definition, goals and performance expectations, and plans (local update). Second, reflection on the learning process itself leads to adaptations to metacognitive knowledge (global update).

The design rationale for the tool, now, is to encourage learners to make informed local and global updates to learning, using self-explication to allow them to inspect their metacognitive processes, and to eventually replace belief-based judgments and predictions by those based on experience (Bjork et al., 2013; Winne & Hadwin, 1998).

3.2 Metacognitive Mechanisms

The mechanisms supporting metacognition during SRL are indicated in the conceptual model (see Figure 5.3). The primary mechanism within the tool was *prompting* learners to *self-explicate* otherwise implicit metacognitive processes and products during different phases of SRL. Five categories of metacognitive processes affecting learning were created: (1) applying metacognitive knowledge to current learning, (2) goal-setting, (3) strategic planning, (4) monitoring and controlling learning by adjusting previous goals and plans, and (5) making adaptations to metacognitive knowledge. As such, three key phases of SRL (2-4) were augmented with applying and adapting metacognitive knowledge (1+5). The organization of learning into five distinct categories containing specific prompts can in itself be considered *metacognitive scaffolding* (6), and further support was implemented as *direct instruction* of particular metacognitive strategies (7).

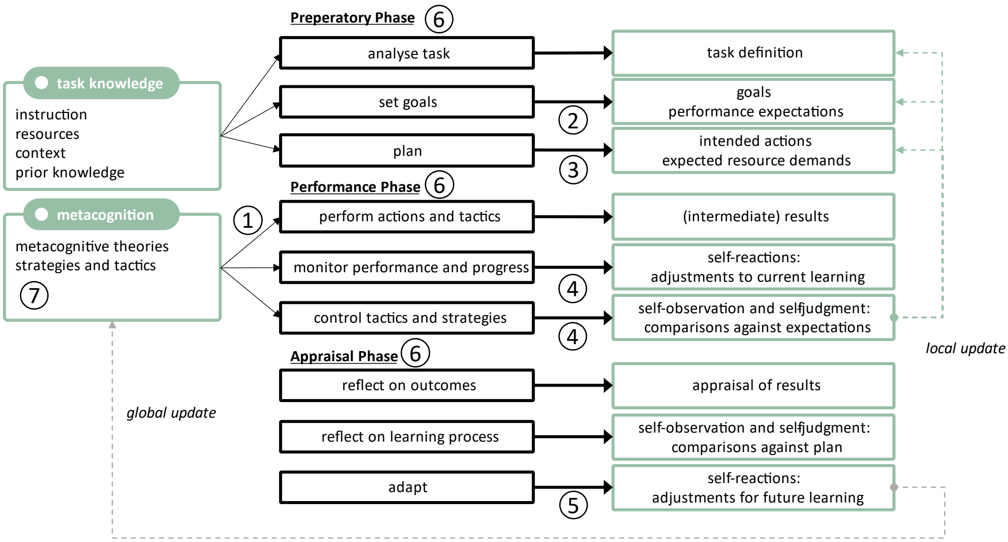


Figure 5.3: Metacognitive mechanisms indicated in the conceptual model.

For each category, a main prompt was created that would ask a learner directly to make a key metacognitive process explicit. To make it easier for learners to understand and respond to the prompts, more colloquial phrasing was used to describe a prompt category (e.g., "ideas about learning", instead of "metacognitive theories", "checks" instead of "monitoring and control", etc.). Within each category, multiple more refined prompts were available to improve the quality of the responses. The refined prompts were created to let learners consider different aspects and perspectives of the current metacognitive process they may not have thought of. Each refined prompt was presented as a question accompanied by an instruction, to provide learners both with an open-ended and a concrete way of responding. The main prompts, refined prompts, and how they relate to metacognitive components of SRL, are shown in Table 5.1.

Table 5.1: Five categories of metacognitive self-explication prompts.

(1) Ideas about learning		
Metacognitive components	*Main prompt*	*Examples of refined prompts*
metacognitive theories strategy knowledge prior knowledge activation	What ideas and expectations do you have about learning?	What will I be doing in this course? What do I already know about how to study effectively in courses like this?
(2) Goals		
Metacognitive components	*Main prompt*	*Examples of refined card prompts*
task definition goal-setting	What are your goals?	What do I want to get out of this course? How well do I expect to do in this course?
(3) Plans		
Metacognitive components	*Main prompt*	*Examples of refined card prompts*
planning for learning resource allocation	What are your plans?	Which strategies worked for me before in other courses? Where can I go if I need help during this course?
(4) Checks		
Metacognitive components	*Main prompt*	*Examples of refined card prompts*
monitoring regulating	What is your progress?	Which activities am I doing to study for this course? Do I need to change my strategy I use to study for this course?
(5) Improvements to learning		
Metacognitive components	*Main prompt*	*Examples of refined card prompts*
updates to understanding updates to learning	What improvements can you make for future learning?	Have I reached the goals I set out for during this course? Which strategies worked or did not work while studying for this course?

Metacognitive support was made progressively available to avoid overwhelming learners and precluding self-initiated metacognitive processing. Per category, the main prompt was always available.

As a secondary mechanism, direct instruction was included to complement self-explication with concrete help, such that eventually most learners would be able to make relevant responses to the prompts. Responding to a prompt, updating a previous response, or otherwise interacting with the tool for a set amount of time, contributed to unlocking further support in the form of cards. Each card either presented one of the refined prompts (6-9 per category) or highlighted a metacognitive strategy (1 per category). The metacognitive strategy cards provided a form of direct instruction by explaining a strategy, when to use the strategy, and examples of how to implement the strategy. Direct instruction was included to complement self-explication with concrete help, such that eventually most learners would be able to make relevant responses to the prompts.

3.3 Implementation

All materials were discussed in a focus group with students in higher education and were reviewed independently by two educational experts. Adjustments to organization, presentation, and wording were made accordingly. The digital tool was then implemented as a web-application, which could be accessed on any device via a browser. A reserved and contrast-rich visual style, including icons as well as text, was used to maximize accessibility and usability.

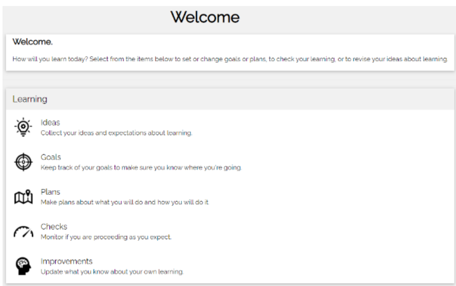


Figure 5.4: Main menu of the tool with the five categories of learning.

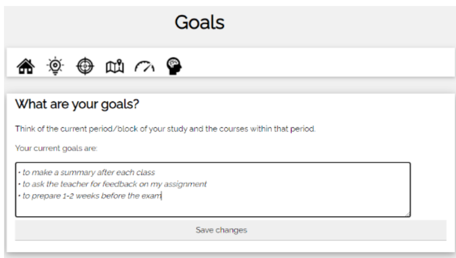


Figure 5.5: Category screen with the main prompt for the goals category.

The main menu of the tool displays the five prompt categories (see Figure 5.4). Learners could freely navigate through the different categories as available and add, review, or update their responses as desired. The tool was offered in either English or Dutch, and learners could adjust this language setting within the tool as desired.

For each category, a separate screen could be accessed from the menu (see Figure 5.5). This screen would display the main question prompt (e.g., "What are your goals?"), an instruction (e.g., "Think of the current period/block of your study and the courses within that period."), and the learner's current response for this prompt (e.g., "Your current goals are:"). Any changes would be saved automatically or when the learner would press the "Save changes" button.

Below the main prompt section, any of the cards with refined prompts were shown (see Figure 5.6). Newly unlocked cards were shown with a sparkling star icon and a green background to draw attention. Learners could write responses to such cards, which would be saved as a chronological series of replies.

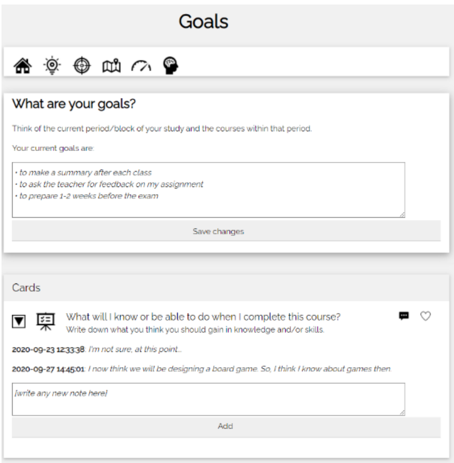


Figure 5.6: Unlocked cards with refined prompts below the main prompt.

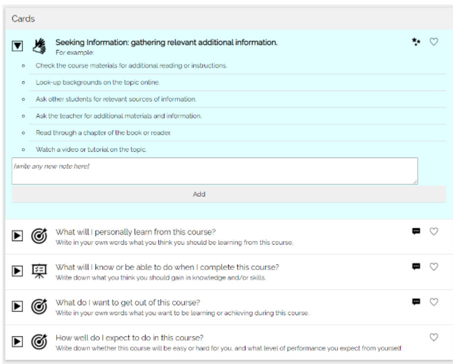


Figure 5.7: An unlocked card highlighting a metacognitive strategy.

When all refined prompt cards for a category were unlocked, one of the metacognitive strategy cards was automatically unlocked (see Figure 5.7). These cards would describe a specific strategy (e.g., "Seeking information: gathering relevant additional information", explain when to use this strategy (e.g., "Use when you feel you need more info before proceeding with the task."), and provide concrete examples of implementing the strategy (e.g., "Read through the chapters of a book or reader.").

3.4 Summary

In summary, the tool was intended to work as follows. The tool prompts learners (i) to make explicit their beliefs about learning, (ii) to explicitly formulate goals and plans for learning, (iii) to explicitly monitor learning, (iv) to make local updates to learning by adjusting goals and plans if needed, and (v) to make explicit any improvements that could apply to similar future learning situations. The tool further allows learners to remain in control and freely navigate back and forth between these prompts to make adjustments as needed. The tool supports learners through refined prompts, that promote them to attend to specific metacognitive aspects of SRL, and altogether improve the quality of their responses. The tool further supports learners through direct instruction of metacognitive strategies. As such, the tool represents a detached form of digital metacognitive support of SRL based on learners self-explicating their metacognitive processes and products.

4. Methods

The objective of this study was to examine how self-explication of metacognition within a detached digital SRL-tool affects metacognition in learners. Additionally, we aimed to compare effects between domain-specific and domain-general metacognitive support. Finally, we wanted to evaluate how learners use and perceive the use of such a tool.

4.1 Study Design

The study was an in-vivo quasi-experiment, with students assigned to experimental groups on a per-class basis. The study adopted a within-subject pre-test/post-test design with between-groups comparisons. Mixed methods were used to collect data, with a primary focus on quantitative and confirmative analysis, and qualitative and exploratory analysis used to identify the underlying motivations and perceptions.

4.2 Intervention

The intervention in this study was the digital tool as presented previously. As part of the experimental condition, the tool could be presented in a domain-specific or a domain-general configuration. In the *domain-specific configuration*, all prompts and instructions were phrased in terms of the domain of learning. Examples of such domain-specific prompts were "What do I already know about game design?", "How can I increase my understanding of game design?", or "When would you use or not use these strategies for learning how to design games?". As such, these prompts instructed students to explicate learning in terms of the domain-specific concepts they were already involved in as part of their study program. This configuration thus bridges the gap between detached support and students' ongoing learning. This configuration of the tool requires that the designers have some knowledge about the subject matter of the educational context in which the tool is used and correspondingly limits when and where it can be used. However, this configuration does not take into account any unique aspects of the subject-matter content: the domain-specificness refers to the phrasing of the prompts, which may be replicated for various educational contexts with limited effort.

In the *domain-general configuration*, a generic phrasing was used, referring to a course without making assumptions about its contents. Examples of the same three prompts in a domain-general phrasing were "What do I already know about the topics of this course?", "How can I increase my understanding of the course material?", and "When would you use or not use these strategies for studying in a course?". These prompts instructed students to explicate learning in more general terms and leave it up to them to make a connection to their ongoing learning. This configuration of the tool can be applied in many educational contexts and incorporates no knowledge of the subject matter.

While the role of the prompts in both configurations is the same, its specific form has implications for the design of the tool and where and when the tool can be applied. Furthermore, we hypothesize that students can use both configurations in a similar way and with similar effects.

4.3 Participants

The participants in this study were 1st-year students of a program in multimedia design at a polytechnic (also referred to as a university of applied sciences) in The Netherlands. Within this program, students prepare for a major in visual design (taught in Dutch to mostly Dutch students) or in game design (taught in English to a mix of Dutch and international students). The default language for communication, instructions, and the tool was based on the main language of the specific major.

From a representative explorative study of metacognition among students of the same program (12% response rate among population, $N = 110$), 69 male, 42 female, and 6 nonbinary, with an average age of $M = 20.8$ ($SD = 3.2$), we found an average metacognitive awareness of 64.1% of the maximum score ($M = 67.7$, $SD = 11.5$), indicating both previous experience with learning and ample room for improvement.

An introductory session was scheduled for each class and 192 participants that completed the informed consent procedure and the pre-test were recruited. Between the pre-test and post-test, 72 participants withdrew from active participation in the experiment, including 3 participants who did not use the offered intervention at all. The number of participants completing the experiment was $N = 120$ (52 female, 66 male, and 2 nonbinary), aged 16-28 ($M = 19.47$, $SD = 2.03$), with 1-4 years of experience in higher education ($M = 1.39$, $SD = 1.08$).

Students in the domain-specific group ($N = 48$) worked with the tool in the domain-specific configuration, while students in the domain-general group ($N = 42$) worked with the tool in the domain-general configuration. The comparison group ($N = 30$) did not work with a digital tool but did receive similar instructions and exercises. This design, with a comparison group lacking only the digital tool, allowed us to examine the added value of the working mechanisms of the digital tool, rather than just the introduction of such a tool in general.

4.4 Measures

The following measures were taken during this study, as outlined in Table 5.2. Via the pre-test questionnaire, we asked participants for age, gender, as well as how many years they had been enrolled in higher education (including the current year).

Additionally, three validated scales were administered: 6 items measured need for cognition (Lins de Holanda Coelho, Hanel, & Wolf, 2018), 19 items measured metacognitive awareness (MAI; Harrison & Vallin, 2018; Schraw & Dennison, 1994), and 10 items measured general self-efficacy (Schwarzer & Jerusalem, 1995). The scale items were presented as statements about learning and participants were asked to express how typical each statement is of their learning, with answering options ranging from 1 ("not at all typical of me") to 5 ("very typical of me").

Table 5.2: Outline of measures taken during experiment.

Pre-Test	**Experimental phase**	**Post-Test**
- demographics (age, gender, years in higher education)	*Intervention Groups:*	
- need for cognition	- metacognitive activities	
	- frequency of use	
- metacognitive awareness	- duration of use	- metacognitive awareness
- self-efficacy		- self-efficacy
- expected performance	*Comparison Group:*	- expected performance
	- none	- evaluation

As we were not in a position to collect participants' previous or future grades, we asked them to predict their learning performance in terms of a grade.

As it is recommended that measures of metacognition are taken in multiple ways (cf. Veenman et al., 2006; Wang, 2015), we combined a scale-based method (MAI) with an observation-based method (log data). The digital tool was equipped with an event logging system, which saved relevant interactions along with a unique user-id and timestamp. From these events, we counted the number of *metacognitive activities* performed within the tool as all updates of ideas, goals, plans, checks, and improvements, as well as any comments made in response to a card. The elapsed time between subsequent events by the same user was also calculated. If this time exceeded the cut-off time of 5 minutes, the usage time was counted as zero. Any event occurring after a gap of this length or longer was marked as a new session. As such, we obtained estimates of *frequency of use* (i.e., number of sessions) and *duration of use* (i.e., total elapsed time within such sessions).

Via the post-test, we measured metacognitive awareness, self-efficacy, and expected performance in the same way as during the pre-test. Furthermore, all participants were asked to rate and comment on how easy, enjoyable, effortful, and useful they found the training received during the study. Additional questions regarding usability, usefulness, and required effort of the tool were presented only to participants in the intervention groups, as were requests for suggested improvements to the tool.

4.5 Procedure

The procedure is outlined in Table 5.3. All communication and all sessions were provided by the same host and provided in the main language of the major of choice.

In the first week, all students received direct instruction on metacognition and beliefs about learning. Instruction explained the relevant concepts and emphasized potential benefits of this approach. The two intervention groups then received instructions to access the tool and log some of their ideas about learning. The comparison groups completed a similar assignment without the tool.

In the second week, a per-class session was scheduled, during which students received direct instruction on setting goals and making plans. Subsequently, the intervention groups completed assignments to set goals and make plans with the tool, whereas the comparison group did so without the tool.

At the beginning of week three, all students were reminded via email to check-up on their previously logged beliefs, goals, and plans, and to make changes or updates as needed. During the third week, the intervention groups received a short assignment during class, asking them to monitor their learning progress and identify improvements for learning using the tool. The comparison group received a similar instruction via email.

The post-test was made available during the fourth week, and students were invited via email to respond. After three days, all students who had not yet responded were reminded to do so. Five days before closing the post-test, a final reminder was sent. A monetary reward of €5,- was offered to all participants who completed the pre-test and the post-test, and attended 50% of the scheduled sessions. All eligible participants who opted to receive the reward were paid in the seventh week.

Table 5.3: Outline of the experimental procedure.

	domain-specific group	**domain-general group**	**comparison group**
Week 1		Session	
		introduction to self-regulated learning and metacognition	
		introduction to the current study	
		informed-consent procedure	
		pre-test	
		direct instruction on beliefs about learning	
	logging beliefs about learning in the domain-specific tool	logging beliefs about learning in the domain-general tool	writing down beliefs about learning
	unlocking domain-specific question and strategy cards	unlocking domain-general question and strategy cards	
Week 2		Session	
		direct instruction on goal-setting and planning	
	setting goals and making plans in the domain-specific tool	setting goals and making plans in the domain-general tool	writing down goals and plans
	unlocking domain-specific question and strategy cards	unlocking domain-general question and strategy cards	
		E-mail	
		reminder to check up on previous beliefs, goals, and plans	
		Session	
Week 3	assignment in class	assignment in class	assignment per email
	monitoring and identifying improvements to learning in the domain-specific tool	monitoring and identifying improvements to learning in the domain-general tool	monitoring and identifying improvements
	unlocking domain-specific question and strategy cards	unlocking domain-general question and strategy cards	
Week 4		post-test	

4.6 Hypotheses and Exploratory Questions

For this study, we have formulated hypotheses as well as exploratory questions. First, we expect a positive effect of using the tool on learning in both the domain-specific and the domain-general configuration:

- H1: metacognitive awareness is increased between pre-test and post-test when working with the tool, and this change is larger than when working without the tool.
- H2: metacognitive awareness is not affected differently by a domain-specific or domain-general tool.

Second, we expect that use of the tool accounts for these effects:

- H3: use of the tool is not different between a domain-specific or domain-general tool.
- H4: use of the tool correlates positively with changes in metacognitive awareness.

Third, we want to examine student perceptions of working with the tool:

- EQ1: which students use, and sustain use of, the tool over time?
- EQ2: how do students perceive the tool in terms of ease of use, enjoyability, required effort, and usefulness?
- EQ3: how do students perceive how the tool affects their learning?

5. Results

5.1 Effects of the Intervention

To assess whether there was a positive within-subjects effect of the intervention on metacognitive awareness, three paired-samples one-tailed t-tests were conducted. Bonferroni-correction was applied to reduce the family-wise error rate.

Table 5.4 shows the results, indicating that on average metacognitive awareness increased within all groups between pre-test and post-test. For the domain-specific and domain-general groups, the confidence intervals of the differences do not contain zero and the effect size is small to medium, however, only the increase within the domain-specific group was significant at an alpha level of .05/3 = 0.017 (H1). The increase in the comparison group is of limited size and the confidence interval contains zero.

Table 5.4: Within-subjects comparison of metacognitive awareness.

	pre-test		post-test						
group	***M***	***SD***	***M***	***SD***	**delta**	**CI** [2]	***t***	***p***	***d***
domain-specific	64.06	9.99	67.71	9.83	3.65	[1.45,5.85]	$t(47)=3.241$	.001	.368
domain-general	64.12	11.66	66.43	10.06	2.31	[.16,4.88]	$t(41)=1.828$	.036	.209
comparison	65.30	8.30	66.00	9.48	.70	[-1.83,3.13]	$t(29)=.549$	.294	.077

Given the quasi-experimental design, we checked and confirmed that metacognitive awareness at the pre-test was not different between the three groups, $F(2,119) = .158$, $p = .854$.

To assess whether the increase in metacognitive awareness scores differed between groups, an ANOVA was conducted on the post-test scores [3]. The assumption of equal error variance was confirmed using Levene's test, $F(2,117) = .080$, $p = .923$. No significant effects of the intervention on the post-test metacognitive awareness scores were found (H2), $F(2,119) = .334$, $p = .717$, $\eta^2 = .045$. Contrasts showed non-significant differences between the domain-specific group and the comparison group (1.708, $SE = 2.29$, $p = .457$), and between the domain-general group and the comparison group (.429, $SE = 2.35$, $p = .856$).

Our analyses regarding need for cognition, self-efficacy, and expected performance did not yield relevant results.

[2] The reported confidence intervals are all bias-corrected accelerated bootstrapped 95% confidence intervals based 1000 bootstrap samples.

[3] Alternative analyses of the delta-scores or with the pre-test scores as a covariate did not produce different outcomes.

5.2 Use of the Intervention

Students within the intervention groups (*N* = 90) worked with the tool for up to 37 minutes (*M* = 9.95, *SD* = 6.54), over the course of 1 through 6 sessions (*M* = 2.87, *SD* = 1.29). The number of metacognitive activities within the tool varied widely (*M* = 8.62, *SD* = 6.37).

Table 5.5: Comparison of usage between domain-specific and domain-general groups.

	d.-specific		d.-general						
measure	***M***	***SD***	***M***	***SD***	**diff.**	**CI**	***t***	***p***	***d***
number of sessions	2.48	1.03	3.31	1.42	.83	[.30,1.34]	*t*(88)=3.197	.002	.676
interaction time	8.91	4.66	11.14	8.07	2.23	[-.60,4.68]	*t*(88)=1.631	.107	.345
metacognitive activities	7.58	5.28	9.81	7.30	2.23	[-.50,4.61]	*t*(88)=1.672	.098	.353

Usage of the tool was compared between the domain-specific and domain-general group (see Table 5.5). The number of sessions within the domain-general group was significantly higher than within the domain-specific group (H3). The interaction time and metacognitive activities were not significantly higher.

Correlational analysis was conducted to assess the relation between use of the tool and the changes in metacognitive awareness. Positive correlations between metacognitive awareness and number of sessions (*r* = .244, *p* = .034), interaction time (*r* = .083, *p* = .434) and metacognitive activities (*r* = .176, *p* = .096) were found (H4).

To examine which students sustained use of the intervention over time, we compared students who completed the pre-test and the post-test (completers) with students who withdrew at some point after the pre-test. Indeed, among withdrawers in the intervention groups (*N* = 43), use of the tool was significantly less frequent, of shorter duration, and with fewer metacognitive activities (see Table 5.6). This indicates that withdrawing occurred not just right before the post-test, but spread out over the three-week period between pre-test and post-test.

The results further showed that withdrawers (*N* = 72) had significantly lower *a priori* metacognitive awareness (*M* = 60.03, *SD* = 10.64) than completers (*M* = 64.39, *SD* = 10.17), $t(190) = 2.829$, $p = .005$, $d = .422$. No significant differences were found for age, years in higher education, need-for-cognition, or self-efficacy. This indicates that sustained tool use is best predicted by higher metacognition (EQ1).

Table 5.6: Comparison of tool use between withdrawers and completers.

	withdrawers		completers					
measure	***M***	***SD***	***M***	***SD***	**CI**	***t***	***p***	***d***
number of sessions	1.74	1.09	2.87	1.29	[.70,1.50]	t(131)=4.918	.000	.912
interaction time	6.67	5.13	9.95	6.54	[1.36,5.15]	t(131)=2.890	.005	.166
metacognitive activities	5.21	5.38	8.62	6.37	[1.35,5.41]	t(131)=3.305	.003	.192

5.3 Perceptions of the Intervention

Participants were asked to evaluate how easy, enjoyable, low effort, useful for themselves, and useful for others they perceived the training to be (EQ2; see Figure 5.8). While no significant differences between groups were found, it appears that students within the comparison group found it easier, more enjoyable, and requiring less effort than students in the intervention groups. Furthermore, it appears that the domain-general group found the tool taking less effort than the domain-specific group.

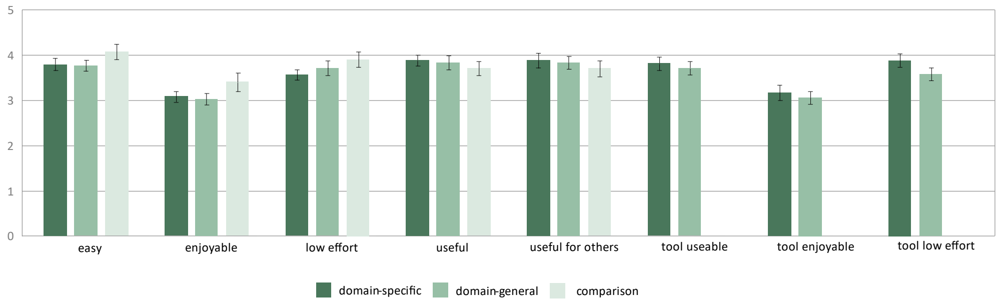


Figure 5.8: Quantitative results of the evaluation questionnaire.

The remarks of the participants in the intervention groups were analyzed to identify perceptions of how the tool affected learning (EQ3). The relative gains in metacognitive awareness between pre-test and post-test, and duration of tool use relative to the average duration, were used to verify whether such perceptions were warranted.

Table 5.7: Reasons for a perceived lack of impact of using the tool on learning, combined with relative change in metacognitive awareness and tool use relative to average tool use.

Reason for perceived lack of impact	**Illustrative quotes**	**MAI**	**Tool Use**
Already knowing how to learn well – either from previous personal experience or from previous explicit training.	"I didn't feel it was of much use to me. I already know how to learn and how to plan well." "Not very much but that is just because my learning style works and doesn't need to change"	+2.2%	+3.4%
No match to the type and level of study activities – these did, according to respondents, not involve much learning but put more emphasis on doing and required not much concerted studying effort.	"Most of the stuff we handle in class is introductory and does not require much learning. Plus, as opposed to high school for example with many different exams, we don't have anything to learn for. All but one subject is learning by doing."	+6.9%	+0.9%
Lack of interest, motivation, or relevance to personal approach.	"I don't really enjoy it because it's not really my thing. I usually don't review my study methods or dive deep in what have I done or not. " "I'm not used to planning for school, which makes forming goals pretty frustrating." "I found it hard to put myself to it, outside of the classes."	+12.2%	+20.1%
Lack of appeal in the design and layout of the digital tool.	"It doesn't look very appealing, too neutral. More people would use it if that was changed." "It was quite difficult to work with the app, and it did not make it appealing to use it – even when I probably could have benefited from it."	+14.0%	+7.5%
Unspecified lack of impact		+4.0%	-0.9%

Four reasons for a perceived lack of impact were identified (see Table 5.7). The perceived lack of impact was corroborated by limited metacognitive gains for the group of students who found they already knew how to learn, as well as for the group of students who found a limited applicability of the tool to the type and level of study activities. However, the perception was not corroborated for the group of students who cited a lack of interest, motivation, or relevance, nor for the group of students who found the tool not sufficiently appealing. Both groups used the tool above average and had substantial metacognitive gains.

Seven ways in which the tool was perceived as having an impact on learning were identified (see Table 5.8). Perceived impact was generally corroborated by substantial metacognitive gains and above average use of the tool. However, limited or negative metacognitive gains were associated with a perceived impact on making plans. Furthermore, a small negative effect on metacognition and below-average use of the tool was associated with a perception of improved ease of learning.

Table 5.8: Clarification of perceived impact of the intervention on learning (table continues on the following page).

Clarification of impact on learning	**Illustrative quotes**	**MAI**	**Tool Use**
Helped me to clarify and to remember what I was expected to learn.	"It often reminded me to do my homework."	+13.7%	+7.3%
	"It makes you think about things you otherwise never really think about. This allows you to become aware of what you can already do, and what you still have to learn."		
	"It made me look carefully, before time, what was expected of me – and I started to make a summary immediately during class, instead of afterwards."		
Helped me to analyze and improve my approach to studying.	"It has helped me to structure my thoughts on the learning process."	+14.1%	+9.0%
	"I have a better understanding of my way of learning, and because of that, I think I can learn more focused and effectively in the future. I am far from being there, but I am now on the right track."		
	"I am more aware of what strategies I should use while I'm learning."		
	"I can now stay calm, and not panic, if there is something I do not fully understand."		

Table 5.8 (continued).

Helped me to set goals, set better goals, and keep track of my goals.	"I find it difficult to set clear goals, but the questions on the cards already made it a bit easier."	+11.3%	+27.5%
	"I set my goals better than I did before, because now I had to think about them in a logical and purposeful way."		
	"By writing them down you can track your progress towards your goals, you can easily see if the things are going well or not so well."		
Helped me to write plans, keep plans, and manage resources for learning.	"It has helped me to set up goals and think about plans on how to work on them, and also to write some ideas that can help."	+3.7%	+9.9%
	"I have started to think better about how I can best deal with my studying materials."		
Helped me to be more retrospective, helped me evaluate and reflect upon what I do.	"It made me more retrospective of my learning."	+12.2%	+26.1%
	"It helped me evaluate my learning skills and find methods and ways to improve on them."		
Made learning easier, clearer, and more effective.	"I made notes on the success of my learning methods and techniques and it did have a result, so I have useful feedback now."	-1.6%	-9.8%
	"I realized that writing down daily tasks and future goals improves my productivity immensely."		
Could be useful for others, who do not yet know how to learn, how to set goals, or anyone who needs help with learning.	"I think the app can be useful for people that could use help to get better at learning, planning and structurizing their school work."	+5.2%	+14.3%

Finally, participants were asked to suggest improvements for the tool. Some respondents indicated no improvements were needed (e.g., "it's good for now" or "it serves its purpose"), while many remarks suggested specific features be implemented (e.g., a calendar of learning activities, using data to identify best practices among students of a course, or the option to adjust or add your own prompts). The most frequently requested feature was an option to receive reminders to check up on learning within the tool. The remaining remarks suggested improvements that are related to the self-explanation approach and detached presentation of the tool, as shown in Table 5.9.

Table 5.9: Suggested improvements to the tool.

Suggested improvements	**Illustrative quotes**
Make it more enjoyable and motivating, by adding rewards, by using gamification, and most prominently by sending regular reminders to form a habit.	"Make it more interesting in some way, most people forget about it as soon as they leave the room."
	"A reminder-feature, that makes you have a look. Now, you have to think of it by yourself, which is easily forgotten (at least by me).
Make it more concrete, by adding tips, examples, and exercises.	"I think it is too general. You have to come up with your goals (problems) and your ways of achieving these goals (solutions) all by yourself."
	"I think it would be nice if it would give more tips on ways to learn."
Make it more specific, by linking it to a course and breaking apart the process more clearly.	"I think it should work together with a course."
	"The questions must be more specific, as well as any follow-up questions."

6. Discussion

In this chapter we investigated the design of detached digital metacognitive support. Self-explication of metacognition across all phases of SRL was compared between a domain-specific and a domain-general implementation. We focused on students in higher education, with specific attention for how learners use and perceive such a tool.

6.1 Conclusions

The results show that a digital tool prompting learners to *self-explicate* learning, in combination with scaffolding and direction instruction, can improve metacognition. Furthermore, in contrast with current recommendations of embedding metacognitive support in domain-specific content, a *detached* implementation of metacognitive support was demonstrated to be effective. However, user feedback underlines that any detached metacognitive support still needs to be applicable to current learning and is preferred to be concrete and specific. Further research on embedded and detached metacognitive support is recommended.

The effect of domain-specific metacognitive support was confirmed, even when learners used the support relatively little over a relatively short period of time. The effect of domain-general metacognitive support could not be confirmed. However, both quantitative and qualitative analysis warrant further research. While the domain-specific tool was more effective, the domain-general tool was used more actively. Perhaps the domain-general approach requires more effort from learners to achieve similar effects, although learners perceived it as slightly easier and requiring slightly less effort. Alternatively, the domain-general support could have appealed more to students. Since domain-general support can be used repeatedly across different learning situations, this type of support has high potential for adoption across a curriculum and, as such, of offering more frequent and diverse opportunities for learners to develop metacognitive awareness.

The results show that use of the tool was limited in frequency, duration, and metacognitive activities. Predominantly, the tool was used during the scheduled sessions and in response to a cue by the host. Correspondingly, participants suggested receiving notifications to attend to the metacognitive support within the tool. Alternatively, a lack of self-initiated use outside of the sessions may be due to a perceived lack of relevance, corroborating results found by Narciss, Proske, and Koerndle (2007) and Jansen et al. (2020). We found this lack of relevance is warranted for a group of students who already know how to learn and did not find much added value in the current tool. Future work could identify what support, if any, could be provided to somewhat proficient learners.

The results also show that students with lower metacognition are less likely to make use of and sustain use of the available support. This signals a key problem with implementing metacognitive support: it is complicated to administer such an intervention to those who would benefit from it the most. While both domain-specific and domain-general digital metacognitive support can be effective, it is a prerequisite that students regularly use the available support. Previous research provides some indications that learners' metacognitive knowledge and skills affect both the quality and quantity of tool use (cf. Clarebout, Elen, Juarez Collazo, Lust, & Jiang, 2013).

6.2 Limitations

In this study we collected insights for a specific group of learners (i.e., young adult students) within a specific educational context (i.e., institutional higher education in The Netherlands). This group of learners is, for example, likely to have previous learning experiences within an institutional context. The phrasing of the prompts used in the present studies is also somewhat specific to this group and context. As such, our findings can be considered relevant for similar situations but may not generalize beyond the studied group.

In this study, metacognition is primarily assessed through a self-report measure and may not accurately reflect actual learning behavior. While learners believed their metacognitive knowledge and skills have improved, only analysis of learning behaviors in terms of activities or performance could provide accurate insights into whether this is actually the case. Furthermore, the metacognitive perspective adopted in this study must be seen within the broader construct of SRL. In the present study, a measure of performance, such as grades, was unavailable and the detached approach prevented observations of learning activities. However, qualitative findings corroborate the quantitative results, providing some indication that learning behaviors were affected. In future studies, measures of performance and learning behaviors should be included to enable a more accurate analysis of the impact of metacognition on learning.

In this study, the domain-specific and domain-general configurations of the tool are studied as two end points of a design dimension. While the domain-general configuration can be viewed as one end point (as it could not be less specific), the domain-specific configuration is not necessarily the most domain-specific configuration possible (as it could be less general). For example, different mechanisms could be introduced that take into account the specific learning tasks and required problem-solving steps to offer more specific support. It would be interesting to further study different configurations to assess what level support is most effective and how domain-specific and domain-general components of metacognitive support interact.

6.3 Future research

The present study confirms that a key challenge for future research is to engage learners with lower metacognition to make use of available support. We foresee two different approaches to address this challenge in future research, with the similarity of leveraging a broader perspective of SRL to improve metacognitive support.

The first approach is to increase tool use by improving the relevance of the support for most learners. Since different learners have different needs for support, this implies that the support needs to be adapted to individual learners. This is possible within a digital tool when there are ways to measure the relevant variables within the tool, for example through self-reported metacognitive knowledge or learning performance. For example, for learners who already know how to learn well, the self-explication of metacognitive strategies could be omitted, however, they may still find it relevant to keep track of their goals and plans. Similarly, support can be adapted to the learning situation. For example, in this study, some learners found the content of the tool mismatched the study level (introductory) and study type (experiential learning). To the extent that such insights about the study context could be incorporated, tools could be made to provide more relevant content.

The second approach is to increase tool use by making it easier and more appealing to make use of the tool. For example, learners could be cued to use the tool through digital reminders sent from the tool or through an intervention by a teacher. However, the goal of self-regulated learning is to self-initiate such activities. Providing such cues are essentially scaffolding the desired behavior, and for self-regulation to occur, should be faded over time. Self-initiated use could be promoted through habit-formation, for example by using gamification to reward behavior and by using cues fading over time to establish self-initiation. Alternatively, self-initiated use could be promoted by increasing perceived task value, for example by providing learners with insights regarding their progress (e.g., demonstrate task value) or by making the support more engaging and motivating (e.g., increase perceived task value). Such research should incorporate motivational aspects of metacognition (e.g., Efklides, 2011, 2014) and address these within the design of the intervention.

Future research and design of digital support of metacognition and SRL should incorporate how learners perceive, value, use, and sustain use of available support on the road towards self-initiated self-regulation of learning.

chapter six

Improving Metacognition with Game-Based Learning

The first experiment described in this chapter is discussed separately in the following conference paper:

Braad, E., Degens, N., & IJsselsteijn, W. A. (2019). MeCo: A digital card game to enhance metacognitive awareness. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th European Conference on Games Based Learning* (pp. 92–100). Sonning Common, United Kingdom: Academic Conferences and Publishing International.

The other experiments describe in this chapter are discussed in the following conference paper:

Braad, E., Degens, N., IJsselsteijn, W.A. & Barendregt, W. (2023). Design experiments in game-based learning of metacognition. *Proceedings of the 17th European Conference on Games Based Learning*, 17*(1)*, 86-93.

Abstract and Research Flow

GBLEs to train metacognition must be carefully designed to effectively promote metacognition and learning, while at the same time inciting and sustaining engagement in students so they make use of it. In the previous chapters, we found that the design of such GBLEs is a complex endeavor, where many design decisions must be made while little guidance is available. In particular, learners with lower metacognition tend to not make use of available tools when given the choice. Here, we seek to increase the motivation to use and keep using such tools using gaming elements.

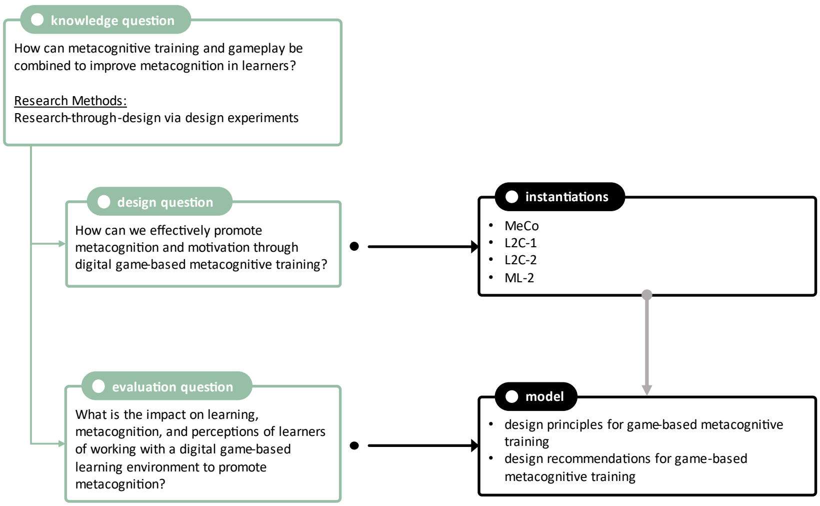


Figure 6.1: research flow for Chapter 6.

The design framework we introduced provides the relevant design dimensions to be considered, but does not offer more concrete design principles to make informed design decisions. Moreover, while we studied some of the instructional design dimensions in the previous chapter, we did not yet study the game design dimensions nor the interplay of both dimensions. Therefore, in this chapter we combine the results of the three previous chapters to address the design of game-based metacognitive training.

First, we formalize and formulate known design principles within the dimensions of the framework. Second, using the research-through-design methodology, we discuss four design experiments where GBLEs for metacognitive training are designed, developed, and evaluated within real-world educational settings. Third, we synthesize the findings into further recommendations for design. As such, this extended chapter contributes to augmenting the descriptive design framework with articulated and prescriptive design principles (see Figure 6.1).

1. Introduction

Imagine that we could offer students an integrated digital GBLE to develop their metacognitive knowledge and skills. Such a GBLE must be carefully designed to effectively promote metacognition and learning, while at the same time inciting and sustaining engagement in students so they make use of it. In the previous chapters, we found the design of such a GBLE to be a complex endeavor, where many design decisions must be made while little guidance is available. In this chapter we combine the results of the three previous chapters to address the design of *game-based metacognitive training*.

In the literature review of Chapter 3 we collected and examined the current state-of-the-art in research on using GBL to train metacognition. We identified various types of integration of metacognition with gameplay (see Table 3.3 on pg. 65), various metacognitive mechanisms that can be employed during GBL (see Table 3.2 on pg. 63), and a number of specific implications for design. In Chapter 4 we introduced the Design Framework for Metacognition in Game-Based Learning (DFM-GBL; Braad, Degens, Barendregt, & IJsselsteijn, 2021; Braad et al., 2019b). The DFM-GBL attempts to help designers navigate the design space of GBLEs for metacognition, by indicating the relevant dimensions in which design decisions need to be made to promote metacognition in learners (see Figure 4.10 on pg. 98). In Chapter 5 we presented the design and evaluation of a digital tool to promote metacognition in learners through self-explication. In terms of the DFM-GBL, this tool provided domain-general instruction, detached from ongoing domain-specific learning, and provided explicit instructions to learners while retaining a high amount of learner control. As such, we collected insights regarding the instructional dimensions of the DFM-GBL, but not regarding the game dimensions, nor regarding the interaction between metacognitive instruction and gameplay.

Therefore, in this chapter, we investigate the relationship between metacognitive instruction and GBL. We apply GBL to metacognitive training with objectives of (1) improving learning and metacognition in learners and (2) motivating learners to initiate and sustain the required effort. While the dimensions of the DFM-GBL indicate the relevant *areas* of decision making in designing instruction and gameplay, the framework does not provide any specific *guidance* to help make such design decisions. Few sources exist that provide recommendations that are specific to the design of *game-based metacognitive training*. Previous research does provide ample advice on the design of metacognitive training in general and on the design of GBLEs in general, and such generic recommendations can often be translated to and used in the design of game-based metacognitive training. It is, however, unsure to what extent these principles will be similarly effective. What is lacking overall is relevant and specific design knowledge that can inform the decision-making process and, as such, refine the design space as defined by the dimensions of the DFM-GBL. The aim of this chapter is to identify, formalize, and formulate such design knowledge to make it easier for designers and researchers to design effective GBLEs for metacognition.

For that purpose, we follow the *research-through-design* approach, and attempt to formulate design assumptions and identify critical design decisions, implement the design as a concrete artefact, and through these artefacts conduct research into the extent to which our design assumptions were confirmed and our design decisions turned out as expected. Through such consecutive research-informed and evaluated design, we seek knowledge about the design itself (Zimmerman & Forlizzi, 2014; Zimmerman et al., 2007).

We will thus propose GBLE designs (to base design choices on previous research findings as much as possible) and subsequently construct GBLE prototypes which enable us to conduct design experiments (to learn about the effects that occur when learners interact with these GBLEs). From these experiments we formulate what was learned in terms of design knowledge, leading to subsequent prototypes and evaluations, or intermediate-level design knowledge in the form of recommendations.

Specifically, for each design experiment, we first discuss the design of the GBLE and its underlying design rationale in terms of the dimensions of the DFM-GBL and in terms of which design principles were applied. As such, we articulate the (assumed, proposed, could-be) design knowledge, unpacking its complexity in terms of the underlying rationale as composed from various design principles. Our goal here is to aid other designers and researchers by indicating which design principles are relevant to consider when designing game-based metacognitive training.

Subsequently, for each design experiment, the evaluation and corresponding results are discussed, providing relevant insights on how learners perceive, use, and are affected by our GBLEs. As such, we examine how a design, as a whole rather than its components, is perceived by and has effects on learners. Our goal here is to identify effects in terms of metacognition and learning, as well as of motivation and usage.

At the end of the chapter, we will return to the DFM-GBL and provide recommendations for designing game-based metacognitive training. We thus regard the designs as different samplings of the DFM-GBL as applied to the design of concrete artefacts. As such, we articulate the (identified, evaluated, should-be) design knowledge that we offer to future designers and researchers involved in designing GBLEs for metacognition. Additionally, we will discuss more generic implications of our findings for the design of GBLEs for metacognition.

Thus, the remainder of this chapter introduces the design principles, presents four design experiments, and finishes with a discussion of design knowledge in relation to the DFM-GBL and implications for future design and research.

2. Design Principles

To specify which design choices were made, and with what underlying rationale, we will first outline a number of *design principles*. These design principles are collected and presented as the set of premises we will use in the subsequent design experiments. They are not meant to be exhaustive or in any other way complete – this initial collection is only the set of design principles that are relevant to underpin and explain the rationale of the specific designs discussed in this chapter. However, as such, these design principles form an important starting point in the formulation of more generically applicable design principles.

These design principles vary in at least two ways. First, these principles draw from metacognitive training literature (in general), game-based learning literature (in general), and game-based metacognitive training (specifically). As such, their level of formulation and specificness to our design objective varies correspondingly. Second, these principles are sometimes less strongly and sometimes more strongly informed by previous research: they vary from an informed assumption to a relatively established guideline or concrete mechanism. For the sake of simplicity, we use the term design principle throughout, while highlighting the context and relevant literature upon which the design principle is founded.

2.1 Design Principles for Metacognitive Training

Previous research on the design of metacognitive training in general recommends (i) explicitly informing learners of the purpose and benefit of metacognitive training to motivate them to exert the extra effort (*explicit information principle)*; (ii) embedding metacognitive instruction and support in domain-specific learning content to ensure that learners can make the connection (*embedding principle*); and (iii) providing learners with ample opportunities to practice and improve metacognition (*extended practice and assessment principle*) (Azevedo et al., 2012; Bannert & Mengelkamp, 2013; Broadbent et al., 2020; Lin, 2001; Osman & Hannafin, 1992; Veenman et al., 2006).

The dominant approach in research and practice is to offer domain-specific training and embed instruction in domain-specific learning content. Recall from Chapter 4 and Chapter 5 that domain-general metacognitive training learning has the potential benefit of being applicable across a wide range of learning topics and contexts (*domain-general training principle*) (Derry & Murphy, 1986; Fiorella & Vogel-Walcutt, 2011; Osman & Hannafin, 1992; Schraw, 1998). However, a drawback is that it requires a more complicated far transfer to ongoing learning. Learners will need additional support to be able to identify what metacognitive knowledge and skills can be transferred and to make the connection between detached, domain-general metacognitive training and ongoing domain-specific learning (*domain-general support principle*) (Braad et al., 2019b; Derry & Murphy, 1986; Osman & Hannafin, 1992).

We defined metacognition as referring to an individual's knowledge of learning and ability to apply that knowledge to their own learning (see Chapter 1). It follows that metacognitive training will involve to a large extent an individual effort. Furthermore, learners develop metacognition in different ways and at different rates, indicating a need for individual and, potentially, differentiated training (*individual practice principle*) (see Chapter 3; Mayer, 2016; Nietfeld & Shores, 2011; Osman & Hannafin, 1992; Veenman & Spaans, 2005; Veenman et al., 2006).

2.2 Design Principles for Game-Based Learning

As discussed in Chapter 1, previous research of domain-specific GBL recommends intrinsic integration of learning content with gameplay (Habgood & Ainsworth, 2011; Ke, 2016; Plass et al., 2015), such that playing the game implies working towards the learning objectives (Arnab et al., 2015; Lameras et al., 2017; Shelton & Scoresby, 2011; Van Eck & Hung, 2010). Intrinsic integration thus attempts to unite the GBL activities of learning and playing, with the goal of fostering both learning and motivation rather than addressing each with separate design elements or mechanisms (*intrinsic integration principle*) (see Chapter 1: Introduction; Arnab et al., 2015; Carvalho et al., 2015; Habgood, 2007; Habgood & Ainsworth, 2011; Ke, 2016)

Recall from the introduction on GBL in Chapter 1 and the literature review in Chapter 3 that, as an alternative to intrinsic integration, learning and playing can be combined in an exogenous way: when learning and playing are alternating activities (*alternating activities principle*). The risk is that learners are not sufficiently engaged, as learning and playing are now more separate (Rieber, 1996; Squire, 2006). To ameliorate the risk of disengaged learners, the learning and playing activities can still be designed such that they align in terms of overall goals (*alignment principle*) (see Chapter 1 [Introduction]; Arnab et al., 2014, 2015; Bedwell et al., 2012; Hung & Van Eck, 2010; Lim et al., 2013).

Recall that in the introduction to GBL in Chapter 1 we summarized how gameplay can be constituted from challenge and corresponding game mechanics and narrative elements. Challenge can contribute to learning by providing increased engagement to play and learn, as well as affect learning directly (*challenge motivation and learning principle*) (Hamari et al., 2016; Malone & Lepper, 1987). Challenge was also found to mediate an increase to metacognitive awareness during GBL (Sun-Lin & Chiou, 2017). The in-game objectives, actions, and corresponding responses by the game, such as reward, punishment, and feedback, can also contribute to motivation and engagement as well as to learning (*game mechanics motivation and learning principle*) (Arnab et al., 2015; Carvalho et al., 2015; Ke, 2016; Malone & Lepper, 1987). The narrative setting, plot, events, and characters within a game can contribute to motivation through fostering fantasy and curiosity, while contributing to learning by offering a cognitive framework created through metaphor and analogy (*narrative motivation and learning principle*) (Barab et al., 2005; Dickey, 2019; Malone & Lepper, 1987; Van Oostendorp & Wouters, 2017).

In skill-based games, over time, players will become more skilled at playing the game. Correspondingly, we must ensure that the progressively more skilled player remains challenged through progressively more difficult gameplay (*game flow principle*) (Hamari et al., 2016; Paras & Bizzocchi, 2005; Schell, 2019).

The social component of GBL provides a powerful mechanism for motivating learnings to engage with the learning content (*social incentive principle*) (Przybylski, Rigby, & Ryan, 2010; Ryan, Rigby, & Przybylski, 2006; Steinkuehler & Tsaasan, 2019). The social context and social presence of others adds to the motivational pull of play (Gajadhar et al., 2008). As discussed briefly in Chapter 1, competition or cooperation within games can offer a specific type of social incentive for players to engage with the gameplay (Barab, Dodge, Tuzun, Job-Sluder, et al., 2007). Competition is known as an effective motivational mechanism for learning in general (Burguillo, 2010), as well as for GBL in specific (*competition principle*) (C.-H. Chen, Shih, & Law, 2020; Malone & Lepper, 1987; Sanchez, 2017), providing challenge and may provide a social incentive to spend more time playing (Malone & Lepper, 1987; Sanchez, 2017). While (friendly) competition seems to positively affect motivation to learn (Aldemir, Celik, & Kaplan, 2018; Zainuddin, Kai, Chu, Shujahat, & Jacqueline, 2020), this effect appears to be more beneficial to above-average learners (Ter Vrugte et al., 2015) and dependent on the subject matter (C.-

H. Chen et al., 2020). A combination of collaboration and competition can more generally contribute to learning as well as motivation (*collaboration/competition principle*) (Ke, 2008c; Malone, 1981; Malone & Lepper, 1987; Plass et al., 2015; Sanchez, 2017; Ter Vrugte et al., 2015).

2.3 Design Principles for Game-Based Metacognitive Training

As discussed in Chapter 3, previous research on designing game-based metacognitive training is sparse. Nonetheless, useful advice is provided by Nietfeld & Shores (2011) (recommendations for stimulating metacognition as part of SRL), Mayer (2016) and Hacker (2017) (recommendations for promoting metacognition within domain-specific GBL).

Nietfeld and Shores (Nietfeld & Shores, 2011) stipulate that supporting all three SRL-phases (e.g., planning, performance, and evaluation) is necessary to allow learners to apply evaluation outcomes to subsequent learning phases and help them to develop and improve metacognition (*learning cycle principle*).

Collaboration within GBL seems beneficial to most learners (Romero et al., 2012). The affordances of GBL for collaboration, for example with virtual companions or advisors (White & Frederiksen, 2005, 1998) or in interaction between learners (Usart, Romero, & Almirall, 2011) are effective ways to promote metacognition (*collaboration principle*) (Lin, 2001; Mayer, 2016; Nietfeld & Shores, 2011). Such pedagogical agents need not be realistic in a visual way in order to be effective (*non-realism principle*) (Mayer, 2016).

Developing metacognition requires an additional (initial) effort of students (Veenman et al., 2006), while at the same time GBLEs can be complex environments requiring learners to monitor and regulate various aspects of learning and playing (Azevedo et al., 2012). Reducing the risk of cognitive overload of the learner must thus be actively considered within the design of GBLEs (*cognitive load principle*) (Kalyuga & Plass, 2009).

Recall from the literature review of Chapter 3 that we identified a number of effective metacognitive mechanisms for GBL (see Table 3.2 on 63). While direct instruction of metacognition is known to work well for novice learners, training through questioning, feedback, and scaffolding may be more suitable for more experienced learners (Bannert & Mengelkamp, 2013; Veenman et al., 2006). A well-known metacognitive training mechanism is to ask learners to self-explain how they approach learning (*self-explanation principle*) (Bannert & Mengelkamp, 2013; Lin, 2001; Mayer, 2016; Osman & Hannafin, 1992). For example, learners can be encouraged to discuss their learning process with other learners, thus requiring them to self-explain (Lin, 2001; Usart et al., 2011), or learners can be prompted to self-explain a specific step or outcome during learning (Bannert & Mengelkamp, 2013; Castronovo et al., 2018). Recall from the literature review in Chapter 3, and specifically the study in the previous Chapter 5, that we identified self-explication of different aspects of learning as an effective mechanism to increase metacognition (*self-explication principle*) (Braad, Degens, Barendregt, & IJsselsteijn, 2022). In addition to metacognitive prompting, we also found examples of embedding metacognitive feedback within gameplay as an effective metacognitive mechanism (*metacognitive feedback principle*) (Snow, Jacovina, & McNamara, 2015; Verpoorten, Castaigne, Westera, & Specht, 2014).

Encouraging learners to model their own approach after how learners approach their learning is a well-known metacognitive instructional strategy (Hartman, 2001b). Moreover, this approach of identifying with someone else's approach was successfully used in the context of GBL (*social identification principle*) (Kim et al., 2009; White & Frederiksen, 1998). Additionally, social reinforcement is a well-known motivational mechanism (cf. Bandura, 1977, 1986) that relates to games (Malone, 1981) as well as metacognition (Zimmerman, 1990). In other words, seeing other learners act and interact within the GBLE increases the likelihood of learners to engage in similar learning behaviors (*social reinforcement principle*).

2.4 Design Principles in the Design Framework

The DFM-GBL describes the dimensions for designing metacognitive instruction and gameplay. The design principles compliment these dimensions with prescriptive advice (see Table 6.1 and Table 6.2).

Table 6.1: Overview of the design principles as part of the DFM-GBL dimensions for instruction (table continues on the following page).

Design principle	Definition
(1) To what extent is metacognitive instruction domain-general or domain-specific?	
domain-general training principle	domain-general training can be applied to a wide range of domains and learning content and thus offers learners more frequent and more diverse opportunities to practice metacognition
domain-general transfer support principle	domain-general training must help learners to make the connection to domain-specific and ongoing learning by identify transferrable metacognitive knowledge and skills and promoting this transfer
(2) To what extent is metacognitive instruction embedded within or detached from domain-specific content?	
embedding principle	embedding metacognitive training in domain-specific learning content makes it easier for learners to make the connection
(3) To what extent is metacognitive instruction explicit or implicit about what a learner needs to do?	
explicit information principle	informing learners beforehand of the goals and benefits of metacognitive training emphasizes its usefulness and motivates learners to invest the required effort
self-explanation principle	stimulating learners to self-explain their problem-solving process and ways of thinking helps them to develop and improve metacognition
self-explication principle	stimulating learners to make explicit their assumptions about learning and choices during their learning process helps them to develop and improve metacognition
metacognitive feedback principle	providing learners with feedback on their metacognitive activities helps them to develop and improve metacognition
(4) To what extent is metacognitive instruction controlled by the system or by the learner?	
extended practice and assessment principle	providing learners with enough time, prolonged training, and frequent opportunities to assess comprehension is required for learners to develop and automate metacognition
learning cycle principle	supporting all three SRL-phases of planning, performance, and evaluation is required for learners allows learners to apply evaluation outcomes to subsequent phases and helps them to develop and improve metacognition

Table 6.1 (continued).

(5) To what extent is metacognitive instruction intrinsically integrated with the gameplay activities?	
intrinsic integration principle	integrating learning goals and activities with gameplay goals and activities ensures that engaging with the gameplay becomes equivalent with engaging in learning
alignment principle	aligning game activities and goals with learning activities and goals ensures that engagement resulting from gameplay is directed at initiating and sustaining learning
alternating activities principle	combining playing with learning by alternating playing activities and learning activities ensures both types of activities are performed but risks not sufficiently engaging learners to continue playing or learning

Table 6.2: Overview of the design principles as part of the DFM-GBL dimensions for gameplay.

Design principle	Definition
(1) To what extent does the game involve social or individual interactions?	
individual practice principle	as metacognitive development differs between individual learners benefit from individual and personalized training
social incentive principle	social incentives are generally effective at engaging learners with gameplay as well as learning content
social identification principle	social identification, or modeling one's behavior after that of another learner, is an effective mechanism to promote metacognition;
social reinforcement principle	social reinforcement, or the increased likelihood of engage in in behavior as observed in other learners, is an effective mechanism to encourage learners to engage in activities
(2) To what extent does the game involve competition or collaboration between agents?	
collaboration principle	using collaboration between peer learners and/or supervisors and using the affordances of GBL for adding collaboration with virtual companions are effective ways to help learners to develop and improve metacognition
competition principle	competition with other players is an effective mechanism to promote motivation through social incentive and as an additional challenge;
collaboration/competition principle	a combination of intragroup collaboration and intergroup competition is an effective mechanism to encourage learners to initiate and sustain gameplay activities
(3) To what extent does the game involve deliberate or reactive responses from the player?	
game mechanics motivation and learning principle	the challenges and objectives, actions and responses, and feedback can pertain to gaming, to learning
game flow principle	through playing a game, the player will become better at the playing the game and to maintain sufficient challenge (while avoiding boredom and anxiety), gameplay must increase in difficulty as the player progresses (theory of flow)
challenge motivation and learning principle	challenge provided by the system affects learning through increased engagement as well as directly
cognitive load principle	complex gameplay involving choices with many possibilities must be avoided to avoid cognitive overload of the learner
(4) To what extent is the game fidelitous to or fictitious about representing the target learning situation?	
narrative motivation and learning principle	the narrative setting and plot can provide motivation through curiosity as to what has happened or will or could happen next, while at the same time using metaphor and analogy to provide a cognitive framework supporting learning
realism principle	metacognitive training, and in particular pedagogical agents, in games need not be perceptually realistic to be effective

A more detailed overview of the design principles within the DFM-GBL dimensions and corresponding literature on metacognitive training (in general), game-based learning (in general), and game-based metacognitive training (in specific) is provided in Appendix E.

3. Design Experiments

In this extended section, we present four design experiments. In each design experiment, we investigate the relationship between metacognitive training and GBL through specific prototypes that are evaluated with learners in real-world educational settings. As we aim to identify and formulate design knowledge, the design principles serve the role of unpacking the complex rationale underlying each design. Therefore, for each design, this rationale is summarized in terms of the DFM-GBL and in relation to how the design principles were implemented. As such, our DFM-GBL fulfils the role of a *research programme* in the sense of Binder and Redström (Binder & Redström, 2006; Löwgren, Larsen, & Hobye, 2013; Redström, 2011), providing a coherent frame of reference between the design experiments.

3.1 Design Experiment #1: MeCo

As discussed, integrating learning content with gameplay is widely recommended for the design of GBLEs. However, it remains unclear whether such integration is also advisable when the learning content itself concerns metacognition: whether integrating metacognitive training with gameplay is similarly effective as integrating domain-specific learning content with gameplay. Therefore, in this design experiment we discuss the design and evaluation of MeCo, a GBLE designed to intrinsically integrate metacognitive training with gameplay (see Braad, Degens, & IJsselsteijn, 2019a for a more extensive discussion).

Design of the GBLE

MeCo was inspired by the mobile game Reigns (Nerial, 2016) and replicates its mechanic of exploring a dynamically branching story through binary choice-making by swiping cards left or right. However, instead of attempting to manage a medieval kingdom, in MeCo the objective is to learn as much as possible about different planets and their inhabitants by planning, performing, and evaluating space exploration missions. Learning is thus embedded in the narrative and the game mechanics, while the goal of the game is for the player to organize and optimize the process of learning and maximize its yields. As such, the GBLE encourages metacognition about the fictitious learning within the game and, by analogy, about real-world learning outside of the game.

As the core gameplay loop, the game adopts the self-regulated learning cycle of a planning phase, a performance phase, and an evaluation phase. The planning, performance, and evaluation of a space exploration mission aimed at learning thus encourages players to apply their metacognitive skills of planning, monitoring, regulating, and evaluating learning activities. As such, learners are able to express their choices in learning in order to be able to assess its effects on learning.

In the planning phase, players are briefed about the problems on their own planets and what needs to be learned, through an interactive conversation with a senior council member character. Subsequently, players are free to choose a learning goal (e.g., learn about a cure for a peculiar disease), select a planet to learn from (e.g., that experiences similar symptoms), and assemble a crew of four to participate in the mission (e.g., crew with medical knowledge and skills). In this way, players have control over which learning goal to pursue and in what way to pursue that learning goal (see Figure 6.2a), thus simulating the planning phase of self-regulated learning and allowing them to enact metacognition.

In the performance phase, players embark on the mission and interact with the crew members to monitor and regulate the activities employed to learn about the planet and its inhabitants. The game implements a system that dynamically branches the narrative through the binary choices the player makes, allowing players to explore a wide range of possible outcomes while each choice is simple in itself. Monitoring is simulated by crew members presenting themselves to the player with findings and issues occurring as part of the mission, which requires players to assess learning progress. Players can then regulate the learning activities in the mission by swiping the crew member card to the left or to the right to make a choice.

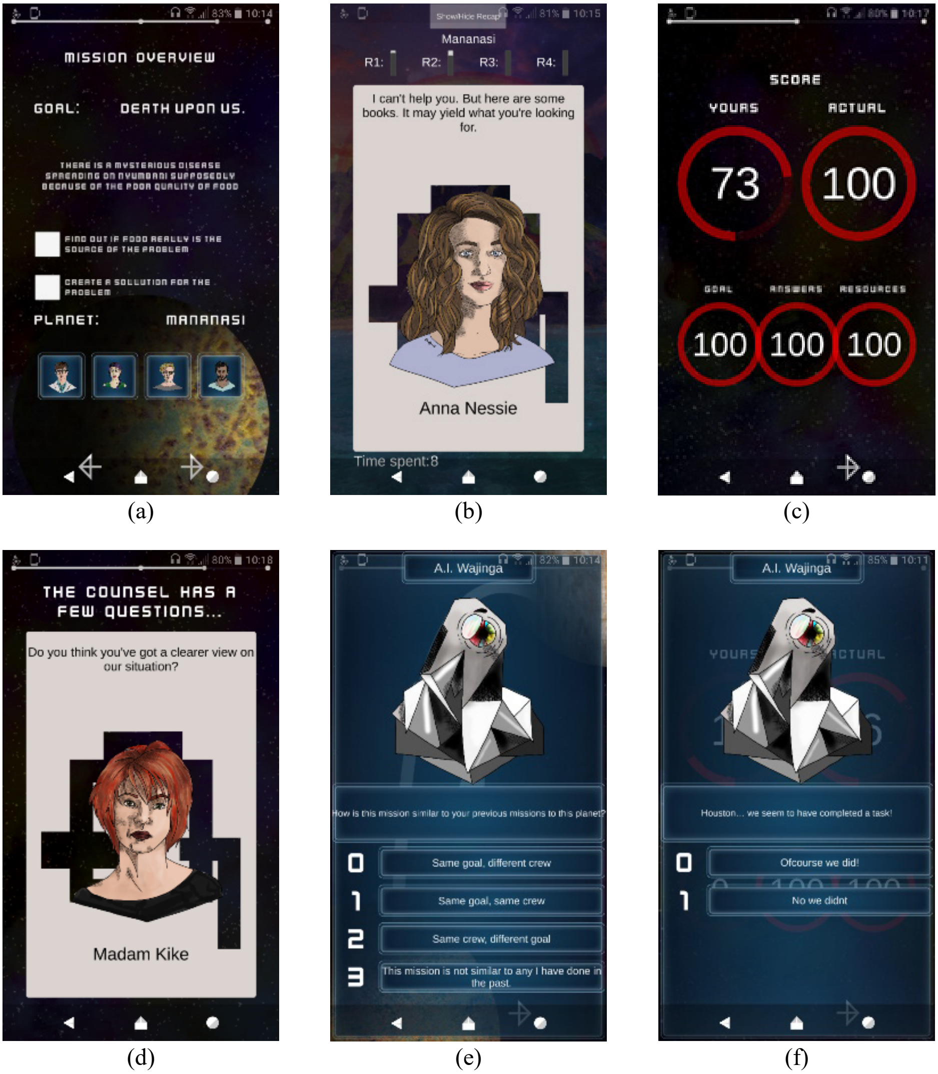


Figure 6.2: An overview of different screens in MeCo: (a) mission overview, (b) metacognitive question during planning, (c) crew member suggestion during performance, (d) senior council member during revaluation, (e) comparison of estimated and actual mission success, and (f) metacognitive question during performance.

This mechanic of choice-making was chosen to allow time for the player to deliberately make a choice between two alternatives after considering all the information and potential consequences. This mechanic thus avoids overwhelming players with too many possibilities and mimics the type of deliberate choice-making of studying metacognitively.

In some cases, crew members will ask for a decision on what the best way is to learn. In this way, the crew members are virtual characters that simulate discussing learning, learning progress, and learning activities as learners would among each other in the real world. For example, at one point a character suggests consulting books as a means of learning, which the player can choose to approve or disregard (see Figure 6.2b): this is analogous to a learner deciding if consulting a book is an appropriate learning strategy given the learning objectives. As such, the game simulates the performance phase of self-regulated learning.

In the evaluation phase, players see a mission recap after which they are asked to make their own estimation of success explicit by indicating a percentage of success on an interactive wheel. In other words: players are asked to evaluate how much was learned during the mission. Immediately afterwards, they receive their actual mission success rating and feedback on whether their self-evaluation was accurate (see Figure 6.2c). In this way, players receive direct feedback (on mission success) as well as metacognitive feedback (on the accuracy of estimating mission success) in a quantitative way (cf. Verpoorten et al., 2014). Finally, the mission is debriefed through a series of reflective questions posed by the senior council member that also provided the briefing. For example, the senior may ask the player if the mission provided more clarity with regard to the learning goals set during the planning stage (see Figure 6.2d). Through this conversation, players explicate their own view of how the mission was performed and why the mission was successful in a qualitative way. In this way, the game simulates the evaluation phase of self-regulated learning and promotes reflection on learning.

To encourage transfer of metacognition from in-game to real-world learning, we implemented various metacognitive question prompts throughout the three phases of the game. These questions are presented to the player by a separate character that is introduced as an artificially intelligent robot assistant to the player. Players can respond to the questions by selecting one of the multiple-choice options (see Figure 6.2e). For example, the assistant robot may suggest that a task has been completed, but the assessment of whether that is correct is left to the player (see Figure 6.2f), thus simulating a metacognitive judgment-of-learning. Another example is when the assistant robot asks the player what could be done differently next time to perform better – thus simulating a learner reflecting on learning activities and outcomes.

Altogether, the design of MeCo thus integrates metacognitive training with gameplay that is analogous to learning, and encourages transfer to real-world learning with metacognitive feedback and metacognitive prompts. For the design rationale of MeCo in terms of the DFM-GBL and design principles, see Table 6.3.

Table 6.3: Design rationale of MeCo in terms of the DFM-GBL and the applied design principles.

Design Dimensions for Instruction	
(1) domain-general/domain-specific: Metacognitive training is *domain-general* to allow the GBLE to be used regardless of learning content. This in turn allows increased opportunities for learners to practice and develop metacognition.	
domain-general training principle *extended practice and assessment principle*	The metacognitive training is not specific to any domain or any learning content. Rather a number of general metacognitive concepts are addressed during gameplay. This allows the GBLE to be relevant to a wide range of learning situations and topics.
domain-general transfer support principle	The metacognitive question prompts encourage learners to reflect upon their in-game choices and to make the connection between in-game choices and real-world learning.
(2) embedded/detached: Metacognitive training is *detached from* domain-specific training to allow the GBLE to be used regardless of learning content.	
~~*embedding principle*~~	The embedding principle cannot be applied because in the case of domain-general training there is no domain-specific learning content to embed metacognitive training in.
(3) explicit/implicit: Metacognitive training is *implicit* in the goals, mechanics, and narrative of the game. This design choice results from integrating metacognitive training with gameplay. A few mechanisms are implemented to make the metacognition explicit in relation to real-world learning.	
self-explanation principle	The metacognitive question prompts encourage learners to reflect upon their in-game choices and to make the connection between in-game choices and real-world learning.
metacognitive feedback principle	Before completing a mission the player is asked to explicitly estimate their success and correspondingly receives metacognitive feedback on their estimation. This mechanism is intended to practice and assess a learner's ability to accurately judge their learning performance.
(4) system-controlled/learner-controlled: The learner has some freedom in the choices they make during the game. For example, a learner can choose the learning goal to pursue and assemble the crew to take on board. These choices represent their choices during a learning process as an analogy. However, metacognitive training is predominantly *system-controlled* as the content and timing of these mechanisms is beyond the control of the learner.	
learning cycle principle	The different phases of the gameplay loop mimic the phases of self-regulated learning and, correspondingly, encourage players to engage in different metacognitive activities in relation to these phases.
(5) extrinsic integration/intrinsic: Metacognitive training is *intrinsically integrated* with the gameplay to foster both motivation and learning.	
intrinsic integration principle	The GBLE attempts to promote metacognition and motivation through the same mechanics, as to avoid their separation in either only learning (risking no motivation) or only playing (risking no learning). Metacognition is integrated with the gameplay by embedding in the narrative (through its setting, storyline, events, and characters) and in the game mechanics (through its goal, its actions and choices, and the outcomes thereof in terms of feedback and rewards).

Table 6.3 (continued).

Design Dimensions for Gameplay	
(1) social/individual: Gameplay is *individual*. This was predominantly a practical choice in the development rather than a consideration regarding metacognitive training or motivation.	
individual differences principle	The GBLE allows learners to individually make their own choices in the way that represents their way of learning. This ensures that the experience pertains to their learning process.
(2) competition/collaboration: Gameplay revolves around combining *cooperation* and *competition* with virtual characters in order to successfully complete the missions. The role of these characters is both motivational and instructional.	
collaboration principle	The characters in the game are designed to offer collaboration or competition without clearly stating this. As such, the player must make a choice without having complete information and then experience and reflect upon the outcomes.
(3) deliberate/reactive: Gameplay emphasizes *deliberate* play through informed and conscious choice-making to promote learners to think about their choices, provide a sense of agency, and to avoid overwhelming players with complexity.	
challenge motivation and learning principle	The core mechanic in the game is deliberate and dichotomous choice-making. There is no time pressure. There is however a challenge to make the right choice in the light of the overall goal of learning about the civilization under study.
cognitive load principle	The core mechanic is designed to prevent overwhelming the player with a continuous environment or many concurrent possibilities. The dichotomous choice-making makes sure the player maintains a sense of control and sufficient resources to attend to metacognition.
game mechanics motivation and learning principle	The challenge and corresponding mechanics in the game are all related to how learning is planned and performed. At the same time the gameplay is designed to be interesting in itself. As such, both motivation and learning are addressed.
(4) fidelitous/fictitious: Gameplay is *fictitious* as it revolves around planning and executing space missions. Gameplay is somewhat *fidelitous* to the learning process in terms of the goals, phases, and through analogy and metaphor.	
narrative motivation and learning principle	Interactive storytelling with dynamic branching is used to provide an interactive experience that can trigger curiosity and surprise in the player and that can be re-played to explore other choices and corresponding outcomes. The narrative is designed to refer to learning by analogy and metaphor and as such offers a cognitive framework for learning. Combined, the narrative is used to encourage motivation as well as learning.
realism principle	The representation is physically realistic at all, as the settings are conveyed with cartoon-like graphics. However, the representation of learning is functionally in line with real-world learning process.

Evaluation

A pilot study was conducted in which the GBLE was evaluated with the aim of assessing its potential for game-based metacognitive training. In particular, we wanted to investigate learner motivation (to use and re-use the GBLE) and metacognitive reflection (on choices in learning). The participants were 7 students in higher education (2 female, 5 male, aged 22-26 years), who played MeCo for approximately 20 minutes. During this time, all participants played two missions.

After playing, all participants completed a questionnaire and subsequently participated in a focus group session. Both the questionnaire and the focus group were aimed at assessing participants motivation to play and continue playing the game, and the extent to which metacognitive reflection resulted from playing the game. The questionnaire contained 30 statements for which the participants indicated to which extent they agreed on a 5-point scale from "strongly disagree" to "strongly agree". The focus group allowed participants to further discuss their experience of playing the game. The focus group was structured by key questions within the same categories as the questionnaire. The focus group was recorded, transcribed, and subsequently summarized in key observations.

Results

Regarding *motivation*, the results from the questionnaire indicate that overall participants were motivated to play the game. Participants indicated that they would like to play again, in particular to explore different outcomes when making different choices: "*I wanted to play it again because I was curious about the other possible storylines*". However, participants elaborated during the focus groups that they would play this game in their free time only if there was a better build-up of characters and if failing a mission would have in-game consequences. They also reported that they felt that their choices in the game mattered while on a mission (performance phase): "*What I specifically liked about this game is making your own choices: I had the feeling I could shape the story, so to speak*". However, after completing a mission, participants were disappointed with the lack of consequences for not performing well (evaluation phase).

In general, the theme, story, mechanics, and humor in the game resonated with the players well enough ("*I really like these kinds of games where you step out of reality and into another world*"), but not necessarily enough to play the game when given a free choice. Some participants suggested that the game would be more interesting for them to play if the link to metacognition and improved learning in the real-world was made more clearly: "*I would want to play the game if I knew it was for learning – perhaps even more so because you get something out of it*".

Regarding *metacognition*, from the questionnaire, it is unclear to what extent players were encouraged to review and reconsider their choices through reflection. Participants reported that they wanted to play again to see what would happen if they made different choices or took on different attitudes. For example, one player indicated that he wanted to compare playing as a nice guy and then as a villain, to see how that would affect outcomes: "*I was curious about the other choices. In the first playthrough you don't really realize that your choices have an impact, but the second time I was looking at 'but what if I do this now?'*".

The robot assistant was implemented to encourage transfer of reflection on in-game choices to real-world learning situations through metacognitive questions. However, the more humorous answering options of the assistant were chosen more often as it directed curiosity of the players towards the response the assistant would give. As such, the assistant was mainly regarded as comic relief, and not as much as a mentor or trainer: "*I didn't really value the robot's answers. It is just a bit of comic relief. I never listened to him*". In this case, the narrative setting diminished the effectiveness of the game, as players did not take the metacognitive questions posed by the assistant seriously: "*I think if that robot is there to make you reflect that it is better if you make it a bit more serious*".

In summary, players did reflect to some extent on their choices within the game and speculated on alternative outcomes in relation to their choices ("*That moment of reflection, where you think, "yes, I haven't thought about that" – but I thought that was very good because then you started thinking about it*"). However, we found no indications that players connected this in-game reflection to real-world learning situations ("*It is just about reflection? I would have liked some explanation about that. If there is a little more emphasis on the reflections it does have potential.*").

Conclusions

The evaluation provided some indications that players were engaged in play and motivated to play the game again. Players initially perceived the deliberate choice-making as meaningful and reported a willingness to re-explore choices in future playthroughs. Learning and metacognition were intrinsically integrated with the gameplay and the SRL-cycle worked well as a core gameplay loop. However, the features added to the game to encourage the transfer of in-game metacognitive processing to real-world learning did not help players to make this link and, instead, they contributed more to motivational than to metacognitive outcomes. This demonstrates how the devil is in the details: for such metacognitive and reflective outcomes, relatively subtle aspects of the narrative setting and characters play a relatively important role in how effective the mechanism turns out to be. Moreover, as the domain-general design includes no assumptions about and takes no measures of any real-world learning, the transfer can only be made by learners themselves. If learners are unaware of the relevance of in-game experiences to real-world learning, and if the prompts are too implicit within the gameplay, this transfer will not occur.

In conclusion, while this GBLE design has the potential to engage learners, we learned that its potential to affect metacognition and, by extension, learning, is too limited. The intrinsic integration of metacognition with gameplay has, in this design experiment, led to metacognitive training being too implicit for learners to make the connection to their real-world learning.

3.2 Design Experiment #2: L2C-1

In the previous design experiment, we integrated metacognitive training with gameplay but found that this approach was too implicit for learners to be able to transfer metacognitive training to real-world learning. Therefore, in this design experiment we discuss the design and evaluation of L2C-1, a GBLE designed to extrinsically combine learning of metacognition with motivation through gameplay.

Design of the GBLE

The learning part of L2C-1 is based on the self-regulated learning cycle. With the objective of encouraging learners to reflect upon and adapt their learning process, the GBLE prompts them to self-explicate learning goals, activities, and strategies and to evaluate these afterwards (see Figure 6.3). The learning part consists of (1) setting a main learning goal and subdividing it into multiple, more specific subgoals; (2) planning learning activities and selecting learning strategies to employ during learning; (3) performing the planned learning activities; (4) evaluating whether the learning activities and learning strategies positively affected learning. When starting a planned learning activity, the GBLE kept track of the planned time and displayed the current goal, subgoal, and strategy.

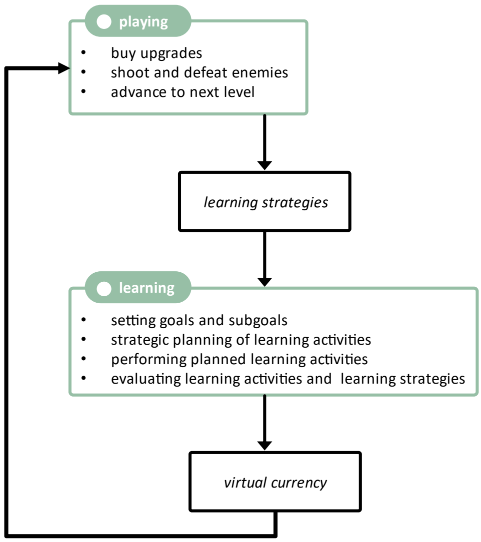


Figure 6.3: Playing and learning loop in L2C-1.

To allow use of the GBLE with any type and content of learning, the design of the GBLE makes no assumptions about what is being learned but, crucially, learners themselves add content that is specific to real-world and ongoing learning. The learning strategies that were included were adapted from Zimmerman & Schunk (1989), Schraw (1998), and Dunlosky, Rawson, Marsh, Nathan, & Willingham (2013). Strategies revolving around planning and goal setting were omitted, as these steps are already part of the workflow within the GBLE. Altogether, 17 learning strategies were included (see Appendix F), such as highlighting (reading through a text while marking the important information), self-consequentiating (thinking of ways in which you can reward or punish yourself for success or failure during the learning process), and seeking social assistance (consulting peers, supervisors, or others to help out with learning).

Through engaging in the metacognitive activities, the user earns virtual currency in the form of gold, which can be spent in the gaming part of the GBLE to advance. As such, the GBLE rewards the effort a learner puts into metacognitive monitoring and regulation with an advantage in the game.

(a) (b)

Figure 6.4: Screens showing (a) the playing and (b) the upgrading part of gameplay in L2C.

The gaming part of L2C-1 is based on Space Invaders (Taito, 1978), where the player needs to defeat wave after wave of opponents by shooting at them (see Figure 6.4). The gaming part consists of (1) buying upgrades with the virtual currency to increase odds of winning; (2) shooting groups of enemy ships; (3) to increase score and advance to the next level.

Table 6.4: Design rationale of L2C-1 in terms of the DFM-GBL and the applied design principles.

Design Dimensions for Instruction	
(1) domain-general/domain-specific: Metacognitive training is *domain-general* to allow the GBLE to be used regardless of learning content. This in turn allows increased opportunities for learners to practice and develop metacognition. The approach of goal-setting, strategic planning, and controlling and evaluating strategy applies to a wide range of learning contexts.	
domain-general training principle *extended practice and assessment principle*	The metacognitive training is not specific to any domain or any learning content. Rather a number of general metacognitive concepts are addressed during gameplay. This allows the GBLE to be relevant to a wide range of learning situations and topics. This in turn allows learners more frequent and more diverse opportunities to practice metacognition.
domain-general transfer support principle	The learning part of the GBLE instructs learners to set goals and subgoals, to plan learning activities and select corresponding strategies, to perform the planned activities, and to evaluate learning as well as strategy use. As such, learners are encouraged to make a connection between domain-general concepts and their concrete, ongoing and real-world learning.
(2) embedded/detached: Metacognitive training is *detached from* (but provided in parallel to) domain-specific training to allow the GBLE to be used regardless of learning content.	
~~embedding principle~~	The embedding principle cannot be applied because in the case of domain-general training there is no domain-specific learning content to embed metacognitive training in.
(3) explicit/implicit: Metacognitive training is *explicit* as the learner is provided with instruction to set goals, plan activities, select strategies, and reflect upon the outcomes thereof.	
explicit information principle	The learner is explicitly informed about the objectives and benefits of metacognitive training with an introductory message. Moreover, the other components of the learning part of the GBLE also explicitly address metacognition.
self-explication principle	The learning part of the GBLE instructs learners to set goals and subgoals, to plan learning activities and select corresponding strategies, to perform the planned activities, and to evaluate learning as well as strategy use. As such, learners make explicit these aspects of learning which would otherwise remain implicit.
(4) system-controlled/learner-controlled: The learner is guided through a *system-controlled*, step-by-step learning process, even though during learning activities little support or instruction is available. The learner does control the content of the GBLE in terms of the goals they set and plans they make.	
learning cycle principle	The different phases of the self-regulated learning cycle form the core of the learning part of the GBLE and encourages learners to engage in different metacognitive activities in relation to these phases.

Table 6.4 (continued).

(5) extrinsic integration/intrinsic: Metacognitive training is *extrinsically integrated* with the gameplay: apart from the outcomes of either feeding into the other, there is no direct connection.	
alternating activities principle *alignment principle*	The GBLE alternates metacognitive activities with gameplay activities, such that metacognition can explicitly addressed without compromising gameplay. To avoid disengaging learners, the two types of activities are aligned with the overall learning objectives – and the outcomes of the activities feed into each other.
Design Dimensions for Gameplay	
(1) social/individual: Gameplay is *individual*. This was predominantly a practical choice in the development rather than a consideration regarding metacognitive training or motivation.	
individual differences principle	The GBLE allows learners to individually make their own choices in the way that represents their way of learning. This ensures that the experience pertains to their learning process.
(2) competition/collaboration: Gameplay revolves around beating the computer-controlled enemies in each level (*competition*).	
competition principle	The gaming part of the GBLE revolves around competition between the player and the computer – or the player attempting to beat the game by clearing each level of enemies.
(3) deliberate/reactive: Gameplay requires responding in limited time to the enemies' movements and attacks (*reactive*).	
challenge motivation and learning principle	The core mechanic in the game is reactive and designed to foster motivation – the gameplay is not designed to contribute directly to metacognitive training. The motivation is intended to stem from achieving a higher score and beating subsequent levels.
gameflow principle	The challenge in the gameplay increases (number of enemies) as the player progresses through the game (level).
(4) fidelitous/fictitious: Gameplay revolves around controlling an abstract spaceship in battle; no attempts to mimic a real-world situation were made (*fictitious*).	
~~narrative motivation and learning principle~~	Apart from a basic setting of a space battle, there is no narrative that contributes directly to motivation or learning.

The enemy ships move horizontally across the screen and, when reaching the left or right border of the screen, move a slight amount down. Each ship shoots downwards at random intervals. Starting with one enemy in the first level, each subsequent level adds one extra enemy to defeat and a special diagonally moving enemy appears in every 5th level. The player controls a ship at the bottom of the screen that can only move horizontally and shoot upwards. The energy of the player's ship decreases when shooting, when getting shot, and when colliding with an enemy ship but regenerates over time towards the ship's maximum. When energy runs out, the player loses the game. When an enemy reaches the bottom of the screen, the player also loses the game. When all enemies are defeated, the player wins this game and will begin the next game at the next level. In this way, the game is designed to provide a challenge that is progressively difficult. The upgrades that can be bought with the virtual currency gained through learning help the player to address this challenge. The game is designed such that all players will eventually require upgrades, such as increasing the energy regeneration rate or the maximum energy, at some point during the game.

Through playing the game, the user unlocks learning strategies which can subsequently be used when planning learning activities. As such, the game links progress in the gaming part to additional options in the learning part. For the design rationale of L2C-1, see Table 6.4.

Evaluation

A pilot study was conducted in which the GBLE was evaluated with the aim of assessing its potential for game-based metacognitive training. In particular, we wanted to assess learner motivation to use and keep using the GBLE, learner perceptions of the usefulness of the GBLE for their learning, and whether learners could understand and apply the metacognitive training to their own learning.

The study was conducted over one session with all participants present (8 students in higher education, 3 female, 5 male, aged 20-25 years). First, the participants were informed of the objectives and procedure of the study and received a 30-minute introduction explaining the relevant features of the GBLE. The participants then worked for 60 minutes with the GBLE as they saw fit, while help from a researcher was available upon request. Finally, the participants took 15 minutes to complete a self-report questionnaire and participate in an interview.

The questionnaire contained 15 statements for which the participants indicated to which extent they agreed on a 5-point scale from "strongly disagree" to "strongly agree". These statements inquired about motivation to use the GBLE, its usefulness for learning, and the included learning strategies. To gather further insights, an interview was held with all participants. This interview was used to complement the questionnaire results through open-ended questions, such as "What did you think of seeing your learning goals and progress?" and "What did you think of having to earn learning strategies through play?".

Results

Regarding *motivation*, none of the participants strongly disagreed with L2C-1 providing motivation through gameplay, however, the interviews revealed that some participants found the game too difficult to play. One participant suggested a different game loop: "*I think [if] you can also earn points/gold by playing the game, [that] would motivate me to play the game more often, as now I just used the app to help me study and didn't care much about winning the game*". The appeal of the game could also be improved: "*Obviously making the game slightly more complex, visually, would also motivate me to play it more often*". Apart from motivation through gameplay, some participants suggested incorporating social features to improve motivation: "*Make it interactive so that friends can link their accounts and compare themselves to each other – maybe even with a cooperative game*". One participant found the gameplay more distracting than motivating: "*While the concept of the tool was good, I think it's a bit silly that you have to play a game before you can get new strategies. This disturbed my attention and distracted me*".

Regarding *usefulness*, more than half of the participants agreed or strongly agreed it was useful to organize their activities with L2C-1: "*I like logging learning goals and subgoals*". Multiple participants mentioned improved insight in estimating and planning time for learning: "*I learned that tasks take a lot longer than you expect. Planning specific time when to study is very useful*" and "*Scheduling your time and finding out and using new or a variety of learning strategies can be useful and fun*". From the interviews, it was found that participants appreciated having a timer while learning as it enabled them to focus on completing the task in time.

Regarding *metacognition*, on average participants were satisfied with the applicability of the provided learning strategies and knowing how to apply them to their learning. However, some participants struggled to use the GBLE when the available strategies could not be meaningfully applied to current learning: "*Not all* *learning strategies were applicable to what I was studying. I couldn't really implement one*". Furthermore, most participants reported becoming more aware of which strategies may be effective, however, only two participants said they had tried out a new strategy and only one participant agreed that they had found new ways to learn.

Conclusions

The extrinsically integrated approach of alternating playing with learning received mixed reactions, although the majority of participants were positive. For learners who enjoyed the game, attempting to advance in the game would eventually require putting effort into the learning part of the GBLE to gain the necessary virtual currency – re-directing their motivation towards learning. However, learners who wanted to use the learning part were required to put effort into playing the game to collect the necessary strategies – drawing their attention away from learning.

The evaluation further identified that, overall, learners found the GBLE useful for organizing and planning their learning, as well as for keeping track of time during learning activities. Although the domain-general design of the GBLE makes no assumptions about the content of learning, the goals and plans as entered by the learners make much of its interactions specific to their current learning. Still, learners could not always meaningfully apply the provided strategies to their current and ongoing learning activities, obstructing the use of the GBLE for learning.

In conclusion, this GBLE design has some potential to motivate learners and affect metacognition. We learned that the extrinsic integration of metacognitive instruction with gameplay, in this design experiment, appears to be a two-edged sword: it may engage learners who would otherwise not perform metacognitive activities, but risks disengaging learners who otherwise would perform them. Participants suggested that, in addition to the individual approach, a social element could help to motivate learners. The training should also be more applicable to ongoing learning by providing relevant learning strategies. Overall, this design and evaluation warrant further research, as the suggested improvements of social features and more applicable strategies can be implemented with reasonable effort.

3.3 Design Experiment #3: L2C-2

In the previous design experiment, we found that the GBLE L2C-1 has the potential to motivate learners and was generally perceived as useful for supporting learning. Therefore, in this design experiment, we further explore this design approach by addressing the suggested improvements and studying its use in a real-world learning context over a longer period of time. This design experiment concerns the GBLE L2C-2 and its potential for game-based metacognitive training.

Design of the GBLE

To address the need for a social element within the GBLE, we implemented a global leaderboard feature where learners could compare themselves to other learners in a competitive way. However, when using competition as a motivational mechanism for learning, care must be taken to decide who competes with whom and on what measures: competing on learning performance may lead to dominance of high achievers while disengaging low achievers (Ter Vrugte et al., 2015). Therefore, the position on the leaderboard was based on the number of different learning strategies used in learning activities. In other words, the incentive structure is designed to encourage trying out new and different learning strategies, rather than to encourage learning performance directly (cf. O'Rourke, Haimovitz, Ballwebber, Dweck, & Popovic, 2014). As such, this feature is a social incentive to try out different strategies, and in this way an incentive that is aligned with the metacognitive objectives. Furthermore, the leaderboard provides a connection between learners and offers an additional challenge within the GBLE.

To address the need for more applicable strategies, we made a step away from the original domain-general approach. As the final assignment for this group of participants was an essay (see below), we added learning strategies specific to writing, as adopted from Graham & Harris (2000). This makes the GBLE less domain-general, as it now also provides somewhat domain-specific support.

For the design rationale of L2C-2, to the extent it is different from that of L2C-1 as shown in Table 6.4, see Table 6.5.

Table 6.5: Design rationale of L2C-2 in terms of the DFM-GBL and the applied design principles (insofar different from L2C-1).

Design Dimensions for Instruction	
(1) domain-general/domain-specific: Metacognitive training is *domain-general* to allow the GBLE to be used regardless of learning content. This in turn allows increased opportunities for learners to practice and develop metacognition. The approach of goal-setting, strategic planning, and controlling and evaluating strategy applies to a wide range of learning contexts. However, the provided learning strategies are *domain-specific* in part: some of the strategies are specific to essay writing.	
domain-general transfer support principle	The learning part of the GBLE instructs learners to set goals and subgoals, to plan learning activities and select corresponding strategies, to perform the planned activities, and to evaluate learning as well as strategy use. As such, learners are encouraged to make a connection between domain-general concepts and their concrete, ongoing and real-world learning. Domain-specific strategies matching the learning content outside of the GBLE make the transfer of metacognitive training to ongoing learning easier to make.
Design Dimensions for Gameplay	
(1) social/individual: Gameplay is *individual*. This was predominantly a practical choice in the development rather than a consideration regarding metacognitive training or motivation. However, learning is now linked to a leaderboard where learners compete for the highest positions (*social*).	
social incentive principle	The GBLE implements a leaderboard where learners can compete among each other for how many different learning strategies have been used. This social incentive is implemented to provide a connection between learners and offer a social incentive aligned with metacognitive training objectives.
(2) competition/collaboration: Gameplay revolves around beating the computer-controlled enemies in each level (*competition*).	
competition principle	The gaming part of the GBLE revolves around competition between the player and the computer – or the player attempting to beat the game by clearing each level of enemies. The GBLE implements a leaderboard where learners can compete among each other for how many different learning strategies have been used.
(3) deliberate/reactive: Gameplay requires responding in limited time to the enemies' movements and attacks (*reactive*). The leaderboard provides a more *deliberate* type of gameplay.	
challenge motivation and learning principle	The leaderboard offers an additional challenge, intended to encourage learners to try out new and different learning strategies.

Evaluation

The purpose of this follow-up study is to study the use of the improved GBLE in a real-world learning context over a longer period of time. Specifically, we investigate (1) the usefulness of the GBLE as perceived by the students and their motivation to use it, (2) how often and how long students make use of the GBLE and how much perceived effort is involved, and (3) strategy use, the perceived applicability of learning strategies, and whether metacognition improved over the experimental period.

Participants

This experiment was conducted among a group of $N = 40$ students (33 female, 5 male, and 2 unspecified), aged 19-29 ($M = 22.1$, $SD = 1.89$), enrolled in an elective course on controversial literature and literary controversy at the University of Groningen. All but four students were majoring in English language and culture, and most of them were currently in the third year of their four-year master studies. As part of their coursework, students were assigned the task of writing a 1,000-word essay describing the controversy associated with a certain piece of literature. From announcement to hand-in, students had four weeks to work on this assignment, during which the study was conducted.

Measures

To assess learners' perceptions of working with this GBLE, a similar self-report measure as in the previous design experiment was used to assess motivation, usefulness, and use of learning strategies. Five questions regarding the required effort within their overall workload were added, to assess to what extent the GBLE takes time and cognitive resources away from studying. Furthermore, open questions inquired about the usefulness of the strategies, the time spent on learning, the approach used for learning, and feedback about the GBLE. Quantitative log data from the GBLE were used to trace learner activities. Frequency and duration of using the GBLE were calculated from the time between logged events, using a 5-minute cut-off point. The metacognitive awareness inventory (MAI; Schraw & Dennison, 1994) was used in the pre-test and post-test to measure participants' awareness of metacognitive knowledge and skills during learning. The MAI assesses metacognitive awareness across eight categories of declarative, procedural, and conditional knowledge, as well as planning, comprehension monitoring, debugging strategies, and evaluation. The MAI was presented as 52 statements to which respondents were asked to indicate their level of agreement.

Procedure

During the four-week period, a weekly lecture was scheduled, with the final hour designated for working with the GBLE. As such, four planned sessions were held: an introduction session, two working sessions, and one evaluation session. Students could use the GBLE as they saw fit during these sessions or at any other time.

During the introduction session, participants were informed of the purpose and design of the study, completed the informed consent procedure, and the pre-test questionnaire. Subsequently, participants were introduced to the GBLE and instructed to use the GBLE while completing a specific essay assignment. During the two working sessions, participants were encouraged to use the GBLE. Support and help were available upon request. Participants were also encouraged to use the GBLE in between sessions. During the evaluation session, we planned to conduct the post-test questionnaire. However, due to the outbreak of COVID-19 and corresponding precautionary measures, the evaluation session was cancelled. To compensate for this, instead, we invited participants to complete the post-test by sending them an email invitation.

Results

While $N = 40$ participants agreed to take part, different numbers of participants are included in each measure: the log data was collected for $N = 33$, the questionnaire responses for $N = 19$ and the post-test metacognitive awareness scores for $N = 12$ participants.

Perceptions

We first discuss learner perceptions of how useful and how motivating they find the GBLE.

Regarding *usefulness*, 33% of the participants agreed or strongly agreed that the GBLE could be helpful for organizing learning, while 34% disagreed or strongly disagreed. Participants liked that the platform "*[...] provides a designated environment where you stay on top of your project*" and appreciated "*its simpleness, it was easy to use and looked nice.*" Some participants found the GBLE useful for their own learning process: "*I liked using the app to log my activities and see how much time I spent studying. I also liked having an overview of different learning strategies and my own goals.*" However, multiple participants indicated that the GBLE would be more useful for first year students: *"I think the idea is nice and it's a fun approach to learning. For people who do not yet have a clear idea of how to learn, it's probably very useful because it allows them to try out different strategies."*

Other aspects that students found useful were help with planning and using both the planning and the timer to demarcate time destined for learning: *"It really helped me to set a timer and force myself to keep working for that entire time. I tend to work a bit haphazardly, so the app helped me become more organized and structured."* Students found it useful "*to plan your activities (since I tend to take a lot of breaks and did not do that in my planned time).*"

Regarding *motivation*, 40% of the participants agreed or strongly agreed that they enjoyed working with the GBLE and playing the game, while 29% disagreed or disagreed strongly. Multiple participants found "*the game pretty fun*" and named playing the game, and getting on the leader board, as the aspect of the GBLE they liked most. In contrast, about the same number of participants found the GBLE "*time-consuming and not very useful for people who are not motivated by games*".

<u>Usage</u>

Second, we discuss usage of the GBLE in terms of time and frequency, as well as the perceived effort of using the GBLE.

Of the 40 students who agreed to take part in this study, only 33 actually used the GBLE. One of the participants used the GBLE for nearly 30 hours in total, spread over 19 distinct days. Without this outlier, on average participants ($N = 32$) used the GBLE from 1 up to 10 distinct days ($M = 3.97$, $SD = 2.71$), in 1 up to 28 different sessions (M = 8.66, SD = 8.21). These participants worked with the GBLE from only 10 minutes to over 7.5 hours in total (M = 1.95 hours, SD = 2.07).

Regarding *effort*, more than 50% of the participants agreed or strongly agreed that the platform required a lot of effort and hard thinking, while 31% disagreed or strongly disagreed. The gaming activities sometimes took more time than the actual studying effort itself: *"I spent way more time playing the game to earn new learning strategies than actually working on my essay. The game was fun, yes, but I feel like I wasted a lot of time on it."*

Of the 33 participants who used the GBLE, only 12 completed the post-test. We examined the high dropout rate. The group composition of the group of completers (11 female, aged 19-24, M = 21.6, SD = 1.38), was not dissimilar to the group of non-completers (17 female, aged 20-25, M = 21.7, SD = 1.46). The *a priori* metacognition of completers (M = 34.0, SD = 8.25) and withdrawers (M = 34.8, SD = 6.40) was also not significantly different, $t(31) = .296$, $p = .769$. While the amount of time spent working with the GBLE among the group of completers (M = 1.76 hours, SD = 1.86) was lower than among the group of non-completers (M = 3.37, SD = 6.34), the difference was not significant, $t(31) = .856$, $p = .287$. The group of non-completers was not less active and most of these participants used the GBLE up until the post-test request.

At least one participant made a deliberate choice to stop using the GBLE: "*I was very distracted by the game and I found it a bit annoying to have to log everything I do for the assignment, so I ended up giving up on it quite early in the process. I already know what works for me in terms of learning strategies, so I found I work better and faster if I just stick to that.*" Otherwise, we think the high dropout is best explained by the outbreak of COIVD-19 and the corresponding measures drawing attention away from our email request to complete the online post-test.

Metacognition

Third, we discuss effects of the GBLE in terms of applying strategies and improved metacognition.

Regarding *strategies*, 31% of the participants agreed or strongly agreed that they could understand and apply the strategies suggested by the GBLE, while 37% disagreed or strongly disagreed. A part of the participants "*found it useful to group strategies by goals*" and liked that the GBLE "*forced me to actively think about the ways in which I approach*" the assignment. However, for most participants this brought little new insight: "*The strategies I did use were useful, but I was already aware of them and using them in my learning process.*"

Students clearly differed in how consciously and how strategically they approach their learning. Where one participant commented that "*Just simply continue doing is always the hardest part for me*", another participant stated that "*I just sat down and wrote it*". Students who attempted to apply the strategies from the GBLE encountered problems related to how well these strategies matched their learning activities at that specific point in time: "*It is not that they were not useful, they just weren't useful for the part of the essay writing process that I was in at that moment.*". Other students were experienced enough to have automated some of their strategy use to the point that they unconsciously selected and applied strategies that had proven to be effective for them: "*It's not motivating to people like me who have established writing routines*" and "*When I gather information, I usually unconsciously come up with the outline I want to use.*"

When metacognitive support required that such unconscious processes were made explicit, students felt they were tasked with superfluous effort without much effect: "*For a third-year student, the app makes essay writing, which I find easier to do now, a bit more tedious. I didn't like having to log what I was doing, I just wanted to do it.*". This emotion was corroborated by the questionnaire: only three participants approached learning differently than usual and only one of them was satisfied with the results. In contrast, only one of sixteen participants who did not change their approach was unsatisfied.

For the participants who completed both the pre-test and the post-test ($N = 12$), a Shapiro-Wilk test showed no significant departure from normality of the MAI-scores at pre-test, $W(12) = .966$, $p = .866$, nor at post-test $W(12) = .935$, $p = .39$. A one-tailed paired-samples t-test indicated no significant increase in metacognitive awareness between pre-test ($M = 34.0$, $SD = 8.25$) and post-test ($M = 35.58$, $SD = 8.49$), $t(12) = .640$, $p = .268$, $d = .185$, CI BCa 95% [-.752,.390].

Conclusions

The GBLE was generally considered to be of added value, in particular to organize learning into goals and activities, and to plan and time learning activities. Learners were now able to meaningfully apply the available strategies to their learning process. The extrinsic integration of learning and playing was received positively in general, even when a simple type of gameplay was used. However, the leaderboard that was introduced as a social incentive to increase motivation played only a limited role in motivation to use the GBLE. As in the previous design experiment, this design worked for the majority of learners, however, others viewed the game as an obligatory waste of time.

Measures of use of the GBLE, both in terms of frequency and duration, indicated participants did use the GBLE regularly and both in response to cues (during the sessions) and, to a lesser extent, in a self-initiated way (outside of class). This corroborates the results for usefulness and motivation of the GBLE. The perceived effort involved in self-explicating learning was relatively high, which may have played a part in the large number of withdrawers during the study.

We did not find a significant increase in metacognition. Some participants were encouraged to think about their approach to learning, and a few tried a different approach than before, but unfortunately without much satisfaction. Thus, while most participants could now meaningfully apply the provided strategies to their ongoing learning, this brought them few new insights. The use of this GBLE was mostly recommended for more novice learners, indicating a potential mismatch between the support offered by the system and the need for support as perceived by learners. The participants of this study were generally more experienced students and possibly had a more developed repertoire of learning strategies, in particular for learning tasks that occurred regularly in their domain of learning. It is possible that for some of these students these learning strategies had become automated and were applied without an aware and conscious consideration. Correspondingly, the suggested strategy was not always used and, instead, learners self-selected an appropriate strategy from their own repertoire. This approach could thus be problematic for learners who already know how to approach learning, as they first need to play the game to unlock a strategy which then may or may not match their intended approach.

In conclusion, we learned that this GBLE design may have potential to motivate learners and affect metacognition, if the effort involved in both learning and in playing can be reduced, while at the same time motivation to use and keep using the GBLE can be improved.

3.4 Design Experiment #4: ML-2

The experiment discussed in Chapter 5 indicates that self-explication of learning can be an effective way of improving metacognition. The previous two design experiments showed some potential for combining self-explication with GBL. However, we also found that use of such GBLEs is limited in duration as well as frequency, and use occurs mostly in response to external cues. Furthermore, we learned that a part of the learners is not motivated by games and regard the effort required for gaming activities as superfluous from the perspective of learning. Therefore, in this final design experiment, we explore whether the design of ML-1 from Chapter 5 can be improved by introducing features that promote motivation to initiate and sustain use of the GBLE, while not demanding the effort of playing through a game as in the previous design experiments.

Design of the GBLE

The design of the GBLE, named ML-2, is based on the same conceptual model and adopts the same principle of self-explication during SRL as the tool discussed in Chapter 5 (Figure 5.2 on pg. 113). To support learners' metacognition throughout the SRL-phases of preparation, performance, and appraisal, four features were implemented: goals, methods, plans, and a logbook. To avoid providing somewhat experienced learners with too basic or too strict advice (as had occurred in Chapter 5 as well as in the previous design experiment), we let learners use these features autonomously when and how they saw fit, while offering explicit instruction through prompts.

The *goals* feature allowed leaners to specify their goals during learning, as suggested by the corresponding prompt: "*What are you trying to accomplish? Which objectives in learning do you have? Here, you can keep track of your goals*.". Learners could further adjust and organize their goals and tick them as complete when accomplished (see Figure 6.5a).

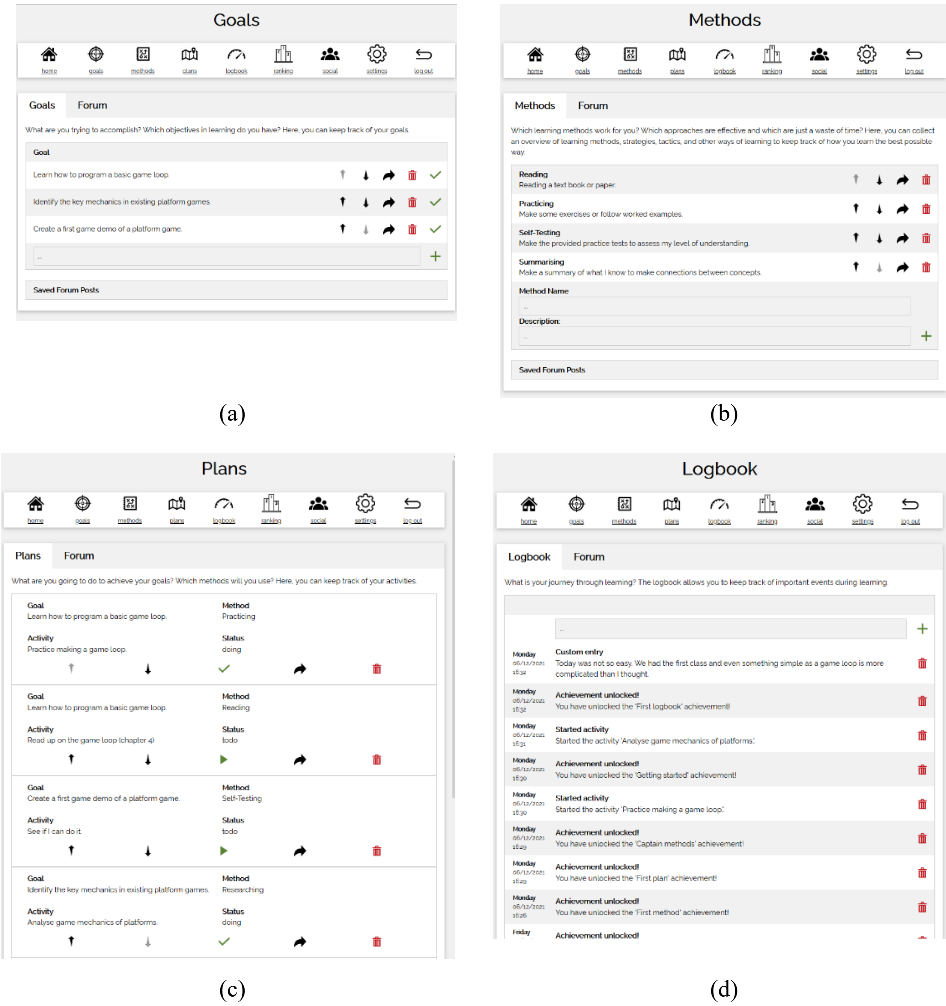


Figure 6.5: Screens for the SRL features of goals, methods, plans, and the logbook.

The *methods* feature allowed learners to specify the different ways of learning they use. The term methods was taken from various conversations with and among students and intended to cover the range of learning strategies, learning tactics, and reoccurring learning activities, without being overly exact. This is reflected in the somewhat extended prompt: "*Which learning methods work for you? Which approaches are effective and which are just a waste of time? Here, you can collect an overview of learning methods, strategies, tactics, and other ways of learning to keep track of how you learn the best possible way.*". Learners could specify a name for the method (e.g., "self-testing") and a brief description (e.g., "making practice tests to assess my current competence") and organize the methods as desired (see Figure 6.5b). During the preparatory phase of SRL, learners could set goals and prepare strategic plans using the goals and methods features.

The *plans* feature allowed learners to make strategic plans: to formulate relevant learning activities in relation to one of the present goals and by employing one of the desired methods. The prompt indicated: "*What are you going to do to achieve your goals? Which methods will you use? Here, you can keep track of your activities.*" The learning activities could be prioritized, and a status-tracking feature allowed activities to be started and, eventually, completed (see Figure 6.5c). During the performance phase of SRL, learners could execute their plans and perform the planned learning activities while monitoring performance and progress, making use of the plans and logbook features.

The *logbook* feature allowed learners to keep track of any relevant occurrences during learning. While some of such events were automatically added to the logbook (e.g., when a goal was completed or when a learning activity was started or finished), learners were encouraged to create their own logbook entries through the prompt: "*What is your journey through learning? The logbook allows you to keep track of important events during learning.*" (see Figure 6.5d). During the appraisal phase of SRL, learners could use the logbook feature to reflect upon learning and make adjustments to goals, methods, and plans as needed.

We implemented features to incentivize acting, interacting, and self-explicate learning within the GBLE. We attempted to combine game design elements from different levels of complexity (Deterding, Dixon, Khaled, & Nacke, 2011), with the objective of appealing to different types of extrinsic and intrinsic motivation (Proulx, Romero, & Arnab, 2017; Przybylski et al., 2010).

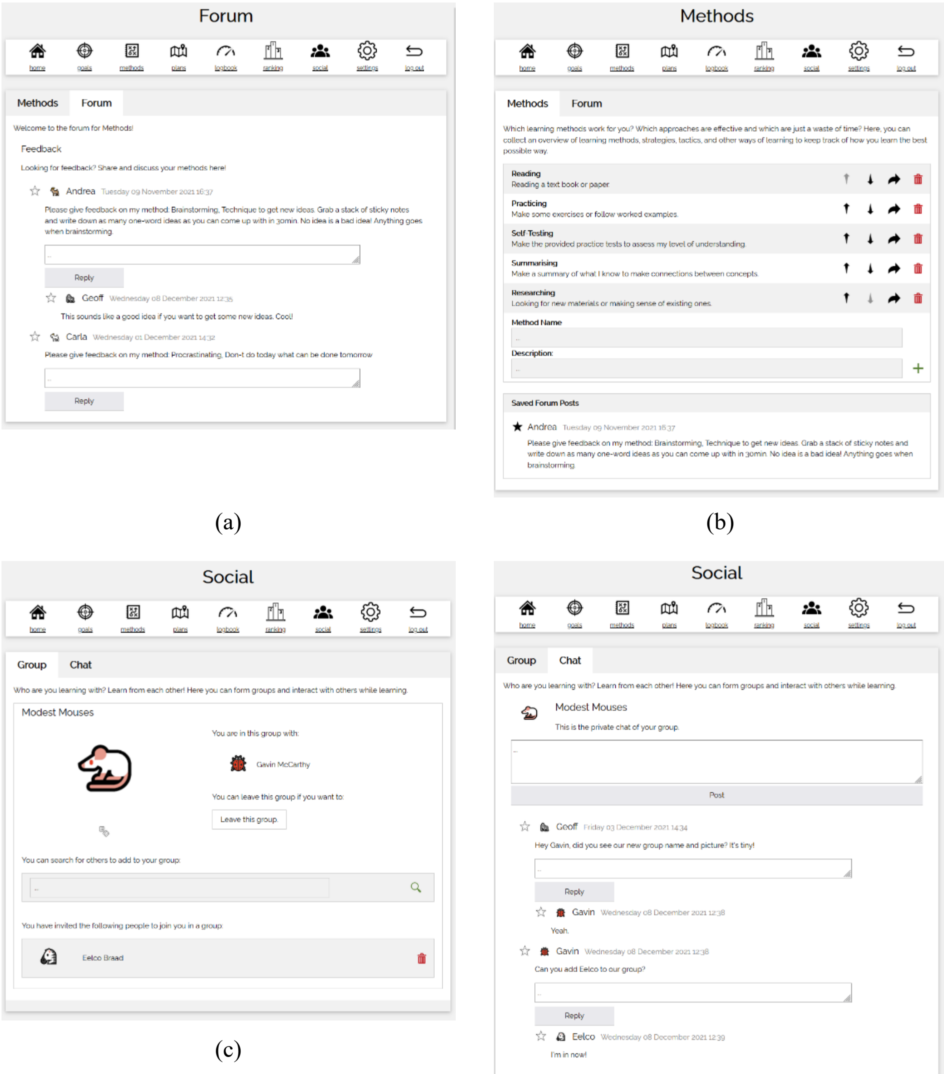


Figure 6.6: Screens for the social features of forums, saving a forum post to show on the category main page, forming a group, and a private group chat.

For each of the four features of goals, methods, plans, and logbook, a dedicated forum was created (see Figure 6.6a). Here, users could exchange insights, examples, and tips. Furthermore, from the corresponding feature page, users could share one of their goals, methods, plans, or logbook-entries, to collect peer feedback through the forums. If a learner found feedback or any other forum post particularly helpful or insightful such a post could be saved, causing it to be shown on the corresponding SRL feature screen for reference (see Figure 6.6b).

Users could form groups with other users by inviting them to join them as a new group or to join their existing group (see Figure 6.6c). A newly formed group was assigned a random name consisting of an adjective and an animal species, which could then be adjusted freely by any group member. The group also was assigned a random profile picture from the predefined list, which could also be changed. Within a group, a chat feature allowed group members to exchange messages while non-members could see or participate in their conversation (see Figure 6.6d).

As an individual user, each learner could collect badges for completing different activities within the GBLE. For example, to provide an early success and demonstrate this feature, after entering a first goal, method, plan, or logbook entry, a user would receive a message announcing a newly unlocked achievement (see Figure 6.7a). The collected badges were displayed in bronze, silver, and gold when unlocked and in black when not yet unlocked (see Figure 6.7b).

As a group member, each learner could also view the badges collected by all group members together (see Figure 6.7c). For unlocked badges, a counter indicated how many of each badge were held by the group. Potentially seeing badges that you do not have collected yourself was intended to spark interest and conversation between group members on how to achieve this.

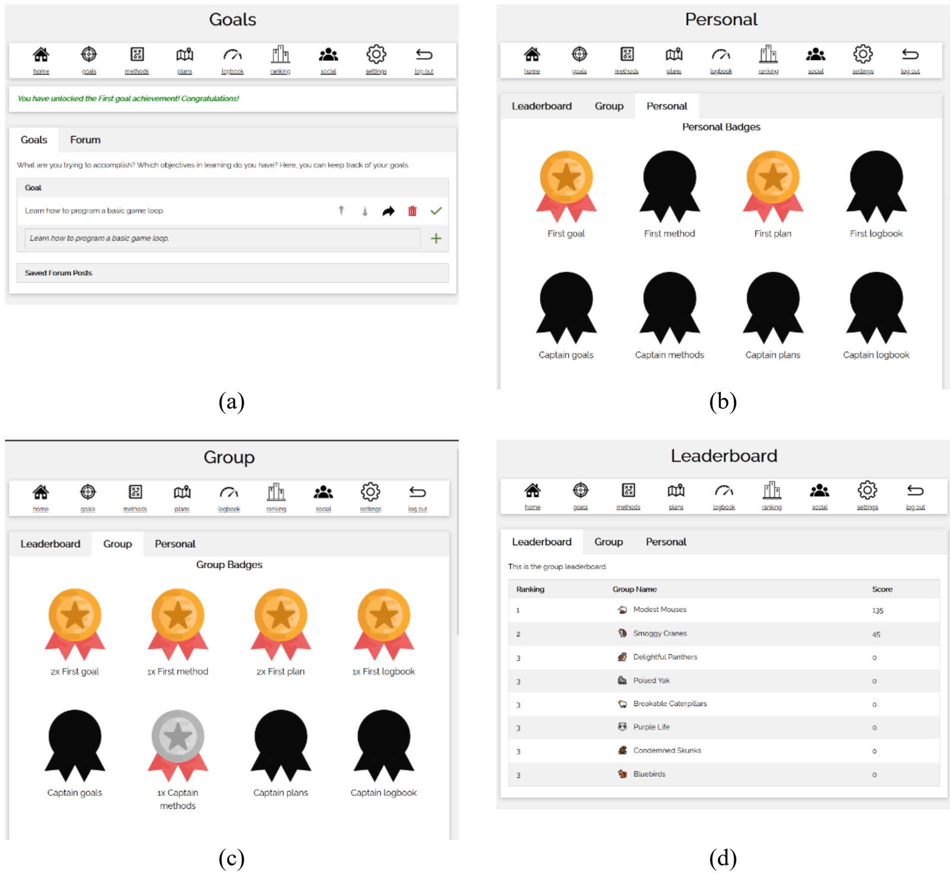


Figure 6.7: Screens for the game features of individual badges, group badges, and leaderboard.

Furthermore, collecting badges together was intended to foster cooperation between group members. The collective achievements of a group were also converted into a score. This score was then shown on a leaderboard, ranking the scores of all groups from high to low (see Figure 6.7d). This leaderboard was available to view for all users of the GBLE that were part of a group and was intended to foster competition between groups.

The tool was intended to work as follows. The GBLE prompted learners (i) to specify their goals, (ii) to identify and describe the methods they foresee using for learning, (iii) to make strategic plans by linking learning activities to goals and methods, and (iv) to monitor progress and performance using a logbook. Learners could exchange ideas and feedback for these features through the forums and chat functionality. Furthermore, it was intended that (i) the announcement of newly unlocked achievements, or seeing such achievements gained by other group members, would encourage learners to see which badges could be collected, (ii) encouraging them to attempt to collect these both individually and as a group. In turn, this was intended to promote learners to (iii) cooperate and discuss within their group and to (iv) collectively compete with other groups for (v) the highest ranking on the leaderboard. For the design rationale for ML-2, see Table 6.6.

Table 6.6 Design rationale of ML-2 in terms of the DFM-GBL and the applied design principles (table continues on the following pages).

Design Dimensions for Instruction	
(1) domain-general/domain-specific: Metacognitive training is *domain-general* to allow the GBLE to be used regardless of learning content. This in turn allows increased opportunities for learners to practice and develop metacognition. The approach of goal-setting, strategic planning, and controlling and evaluating strategy applies to a wide range of learning contexts.	
domain-general training principle + extended practice and assessment principle	The metacognitive training is not specific to any domain or any learning content. Rather a number of general metacognitive concepts are addressed during gameplay. This allows the GBLE to be relevant to a wide range of learning situations and topics. This in turn allows learners more frequent and more diverse opportunities to practice metacognition.
domain-general transfer support principle	The GBLE prompts learners to set goals and subgoals, to plan learning activities and select corresponding strategies, to perform the planned activities, and to evaluate learning as well as strategy use. As such, learners are encouraged to make a connection between domain-general concepts and their concrete, ongoing and real-world learning.
(2) embedded/detached: Metacognitive training is *detached from* (but provided in parallel to) domain-specific training to allow the GBLE to be used regardless of learning content.	
~~embedding principle~~	The embedding principle cannot be applied because in the case of domain-general training there is no domain-specific learning content to embed metacognitive training in.

Table 6.6 (continued).

(3) explicit/implicit: Metacognitive training is *explicit* as the learner is provided with instructions to set goals, plan activities, select strategies, and reflect upon the outcomes thereof.	
explicit information principle	The learner is explicitly informed about the objectives and benefits of metacognitive training within the GBLE. All components of the learning part of the GBLE also explicitly address metacognition.
self-explication principle	The GBLE prompts learners to set goals and subgoals, to plan learning activities and select corresponding strategies, to perform the planned activities, and to evaluate learning as well as strategy use. As such, learners self-explicate their metacognitive view of their own learning.
(4) system-controlled/learner-controlled: The *learner controls* how and when to use the available features, while the *system controls* which features are available and how user input is handled. The learner does control the content of the GBLE in terms of the goals they set and plans they make.	
learning cycle principle	The GBLE addresses all phases of the self-regulated learning cycle with both a self-explication feature and a dedicated forum for sharing feedback and other content. As such, learners are encouraged to engage in different metacognitive activities in relation to these phases.
(5) extrinsic integration/intrinsic: Metacognitive training is *extrinsically integrated* with the gameplay: the gameplay is only loosely coupled to metacognitive instruction through the incentive system that rewards metacognitive activities with points and badges.	
alignment principle	The gameplay goals and the corresponding incentive system aligns directly with the metacognitive objectives: points and badges are achieved by conducting metacognitive activities within the GBLE and the leaderboard position is determined based on points and badges.

Table 6.6 (continued).

Design Dimensions for Gameplay	
(6) social/individual: Gameplay emphasizes *social interactions* through forums, peer feedback, group chat, but supports *individual interaction* to an extent. The self-explication of goals, methods, plans, and logbook entries is individual while each can be shared to collect feedback.	
social incentive principle *social identification principle* *social reinforcement principle*	The GBLE supports various types of social interaction, both to improve metacognition directly and to motivate learners. Learners can interact with other learners through group-forming, group chat, and through exchanging learning approaches and peer feedback via the forums. Furthermore, learners can view which badges other learners within their group have obtained and what scores other groups have attained. As such, they perceive learning activities and game performance from other learners. Altogether, these mechanisms are intended to make a learner feel part of a cohort of learners, to suggest and promote different metacognitive activities and learning approaches, and to foster motivation to use and sustain use of the GBLE.
(7) competition/collaboration: Gameplay combines *competition* between groups (via the leaderboard) with *collaboration* within groups (via the badges system).	
collaboration/competition principle	The GBLE incentivizes metacognitive activities and social interactions through individual and group-based achievement rewards, as well as through a shared leaderboard. The combination of collaboration (within a group) and competition (between group) is intended to contribute to learner engagement.
(8) deliberate/reactive: Gameplay involves only *deliberate* responses; no element of timing is involved.	
game mechanics motivation and learning principle *challenge motivation and learning principle*	The gameplay incentivizes conducting various metacognitive and other activities within the GBLE through points and badges. These achievements, as visualized in individually and group-wise collected badges, offer an incentive through the challenge of completing the set of badges individually and/or as a group. Furthermore, the leaderboard presents a group-based challenge of outcompeting other groups.
gameflow principle	The achievements range in difficulty from easy-to-achieve introductory achievements (that reward first use of a feature), to achievements that emphasize longevity (performing activities a certain number of times) and diversity (performing new activities that require effort).
cognitive load principle	The gameplay is in itself simples and involves no complex decision-making or real-time choices, such that the risk of cognitive overload is reduced.
(9) fidelitous/fictitious: Gameplay is fidelitous to learning; no element of fantasy is involved.	
~~*narrative motivation and learning principle*~~	There is no narrative to support motivation or learning.

Evaluation

The purpose of this study was to investigate a digital GBLE offering metacognitive support within a real-world educational context over a longer period of time. Specifically, three research perspectives were addressed in this study: (1) the perceptions of learners using and not using the GBLE in terms of enjoyment, effort, and usefulness, (2) how often and how long students make use of the GBLE, and (3) whether metacognition improved over the experimental period.

The study was 9-week long in-vivo quasi-experiment, with students randomly assigned to experimental groups on a per-class basis, with an intervention group using the GBLE and a control group not using the GBLE. The study adopted a within-subject pre-test/post-test design and mixed methods were used to collect data, with qualitative analysis used to interpret the quantitative data.

Participants

The participants in this study were 1st-year students across 12 classes of a bachelor program in Creative Media & Game Technology at Hanze University of Applied Sciences Groningen, The Netherlands. The number of participants completing the experiment was $N = 54$ (35 male and 19 female), aged 16-28 ($M = 19.59$, $SD = 2.13$).

The participants in nine randomly selected classes were assigned to the intervention group. The intervention group was provided with instructions to access and use the GBLE throughout the experimental period. In the intervention group, the experiment was completed by $N = 39$ students (26 male and 13 female), aged 16-26 ($M = 19.41$, $SD = 1.956$).

The participants in the three remaining classes were assigned to the control group, with $N = 15$ students (9 male and 6 female), aged 18-28 ($M = 20.07$, $SD = 2.549$) completing the experiment. The control group completed the pre-test and post-test but received no other instructions throughout the experimental period.

Measures

The measures taken during this study were collected through a pre-test questionnaire, focus group sessions, log data from the GBLE, and a post-test questionnaire.

Via the pre-test questionnaire we asked participants to indicate their age and gender. To assess self-determined and non-self-determined motivation to put work into learning, we asked participants to complete the Work Extrinsic and Intrinsic Motivation Scale (WEIMS; Tremblay, Blanchard, Taylor, Pelletier, & Villeneuve, 2009). This scale was originally developed for work settings but can be used across different contexts. From this scale, a score for self-determined motivation as well as for non-self-determined motivation can be derived. Additionally, we asked participants to complete the Metacognitive Awareness Inventory (MAI; Harrison & Vallin, 2018; Schraw & Dennison, 1994). Via the post-test questionnaire we asked participants to complete the MAI again.

From the log data we calculated measures of the frequency and duration of interactions students had with the tool. The frequency of use was calculated as the number of different days the tool was used as well as the number of sessions that was not interrupted for longer than five minutes. The duration of use was calculated as the number of minutes spent in such sessions.

Via focus group sessions we collected insights into perceptions of participants regarding the GBLE. A topic list was used to structure these sessions. An evaluation questionnaire presented after the post-test further collected perceptions of participants within the intervention group.

Participants who indicated that they had used the tool were asked to indicate, on a Likert scale from -2 (strongly disagree) to 2 (strongly agree) whether they found the tool easy to use, enjoyable, requiring little effort, and whether they found the tool useful for themselves as well as for others. These participants were also asked to rate, on a Likert scale from -2 (strongly dislike) to 2 (strongly like) the different features of the tool. Finally, these participants were asked to describe how using the tool had affected their learning.

Participants who indicated that they had not used the tool at all were asked to indicate, on a Likert Scale from -2 (strongly disagree) to 2 (strongly agree) whether they did not use the tool because it was not easy to use, was not enjoyable, would take too much effort, or whether they thought it was not useful for themselves. These participants were asked to describe why they did not use the tool. All participants within the intervention group were asked for suggested improvements to the tool.

Procedure

In the first week, all classes were visited by the same researcher who provided an introduction to metacognition and the present study. In all classes students were asked to complete the informed consent procedure and to fill out the pre-test questionnaire. In the classes assigned to the intervention condition, the GBLE was demonstrated and explained. Subsequently, participants could access the GBLE by creating an account and logging in via a browser on a computer, phone, or tablet.

During this week and the following eight weeks, students were free to use the GBLE as they saw fit. Weekly emails, highlighting different features of the GBLE, were sent to remind students that the tool was available for use.

During the second week two focus group sessions were organized. To make sure that focus group participants were somewhat familiar with the GBLE, they were asked to explore for approximately 10 minutes at the start of these sessions. Subsequently, approximately 30 minutes were used to have a conversation, with one researcher posing topics and questions and an assistant taking notes of what was said by the participants in response to the researcher and each other. At the end of the sessions, an open brainstorm was held to identify potential improvements to the GBLE.

The pre-final week was a fall break and in the final week, the same researcher again visited all classes to ask students to complete the post-test questionnaire and thank the students for their participation. In the following two weeks, further reminders to complete the post-test were sent per email. Among all participants who completed the pretest and the posttest we randomly distributed 8 gift certificates of €25,- each.

Results

Perceptions

First, we discuss the perceptions of learners who used and who did not use the GBLE. Two focus group sessions were held and involved $N = 8$ participants in total. These were volunteers recruited from two of the intervention group classes. The focus group participants agreed that they perceived the GBLE as useful support for learning. However, a slight majority stated they preferred to not use digital tools for learning and, correspondingly these participants found the GBLE less suitable for themselves. One participant remarked that they found the aspect of competition something that interfered with, rather than stimulated, their motivation to learn.

From the post-test responses, $N = 18$ participants within the intervention group completed the questions regarding evaluation of the tool, of which $N = 9$ did and another $N = 9$ did not use the GBLE.

The results from the participants who did use the GBLE indicate that they did not enjoy using it and found that using it involved too much effort. The perceived high effort could in part be due to limited guidance on how to use the GBLE: "*Provide guidance with the methods. I did not understand at all what to write down at the method part, so maybe give examples.*" Furthermore, the focus group findings were corroborated in that the GBLE was deemed useful, but predominantly for others. Some of these participants perceived the writing down and structuring of goals, methods, and plans as positive contributions to learning that provided a sense of structure ("*It helped with structuring your own learning goals*") and control ("*When there were a lot of deadlines and I felt overwhelmed, writing it all down helped*"). For one participant, the GBLE fitted with an intention that was already present: "*I do want to be more thorough with my planning going forward, but that was a goal I had already set for myself*". However, another participant already had found ways of achieving that: "*I already use other tools to track what I need to do*". The features implemented to promote use and sustained use of the GBLE did work for some of these participants: "*It motivated me a little*". However, more relevant content, such as suggested strategies, could have helped retain specific users as well: "*I would have loved to see different strategies already prepared when first using the tool*".

The results from the participants who did not use the GBLE indicate that enjoyment did not play an important role in their choice. However, the required effort (too high) and perceived usefulness (too low) were important reasons to not make use of the GBLE. Regarding effort, participants found they were too busy with other study-related activities: "*I was too busy with assignments and learning to use the tool as well*" and "*There was, in total, too much stuff for me as a first-year student*". The effort of writing out goals, strategies, and plans also had a negative impact on use: "*The time and effort to put my tasks into the system – and then after putting them in it was hard to follow through*". Regarding usefulness, some participants decided that using the GBLE was not worth the effort ("*I felt like it was not worth using*") or did not find they needed it ("*I did not feel like I needed it*"). Others found it confusing the use the GBLE ("*It seemed confusing to use at first, and that for a tool that aims to help with organizing and planning*") or were disappointed in their expectations ("*The feature to check out other peoples' strategies felt interesting and useful but wasn't really in the end*"). The game features implemented to promote the use and sustained use of the GBLE did not convince this group of participants to use it: "*There was no bigger motivation behind the tool. The achievements were not enough of a reward*". However, the reason for not using the GBLE that was most often given was simply forgetting about it ("*I just forgot about it actually*") or forgetting about it because it did not seem too useful ("*I initially wasn't too interested in using the tool and eventually forgot about it*").

<u>Usage</u>

Second, we discuss usage of the GBLE in terms of time and frequency. We analyzed data for $N = 29$ participants who used the GBLE according to the log data. On average, these participants used the tool for up to 125 minutes ($M = 17.473$, $SD = 27.119$). Usage was spread over 1 to 5 distinct days ($M = 1.31$, $SD = .081$) and distributed over 1 to 5 sessions ($M = 1.79$, $SD = 1.236$), with the majority of participants using the GBLE only on a single day and in a single session (see Figure 6.8).

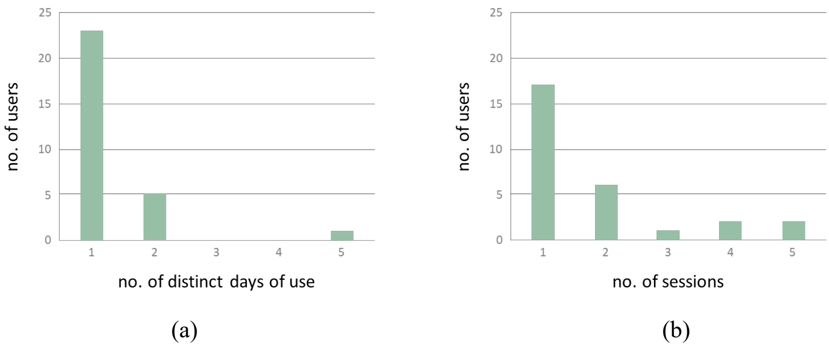


Figure 6.8: usage of the GBLE across (a) distinct days and (b) different sessions.

Only 5 groups were formed, involving only 11 of the users. Use of the forums was limited to 11 posts and 6 replies among 8 of the users. Only a few of these interactions related to learning, while most were initial messages to see how this feature worked.

Only *N = 29* participants of the intervention group did make use of the tool during the experimental period. The substantial number of 67% non-users could not be explained in terms of different *a priori* metacognition, $t(86) = -.236$, $p = .857$. *A priori* self-determined motivation also did not differ between users and non-users, $t(86) = -.236$, $p = .814$, nor did non-self-determined motivation, $t(86) = -.873$, $p = .385$.

Metacognition

No significant *a priori* differences between the control group and intervention group were found in terms of age, pre-test MAI-scores, self-determined or non-self-determined motivation. A Shapiro-Wilk test was conducted to verify that post-test metacognitive awareness scores were normally distributed for the control group ($p = .438$) and the intervention group ($p = .135$). Levene's Test confirmed equal error variances, $F(1,52) = .264$, $p = .610$.

We conducted a mixed factorial ANCOVA with the experimental condition as a between-subjects factor and the pre-test metacognitive awareness scores as a covariate. As expected, the pre-test MAI scores had a significant impact on the difference of post-test MAI scores between the two conditions, $F(1,51) = 91.763$, $p = .000$, $\eta^2 = .643$. However, no significant effect of the experimental condition itself was found while accounting for pre-test scores, $F(1,51) = .319$, $p = .575$, $\eta^2 = .006$.

One-tailed paired-sample t-tests were then conducted on the pre-test/post-test contrasts of metacognitive awareness per group. In the intervention group ($N = 39$), between pre-test ($M = 62.79$, $SD = 8.974$) and post-test ($M = 64.95$, $SD = 10.650$), metacognitive awareness significantly increased, $t(38) = 2.077$, $p = .023$. The effect size was a Cohen's $d = .333$, BCa 95% CI [.205,.4.307]. In the control group ($N = 15$), between pre-test ($M = 65.40$, $SD = 12.351$) and post-test ($M = 68.40$, $SD = 11.957$), metacognitive awareness did not significantly increase, $t(14) = 1.607$, $p = .065$. The effect size was Cohen's $d = .415$, BCa 95% CI [-.598,6.665].

Conclusions

On average, use of the GBLE over the experimental period was very limited in frequency: most participants used it only a few times. Duration of use varied widely and up to two hours in total, however, was approximately limited to a quarter of an hour on average. Social interaction in terms of group-forming or interactions via forums was also very limited. We found a substantial drop-out of participants during the study but could not explain this in terms of *a priori* metacognition or motivation. Altogether, we can conclude that a potentially positive effect of using the GBLE on metacognition was not achieved for most students. The limited use of the tool, in terms of frequency and duration, prevents any strong conclusions regarding its effects on metacognition.

While we did not find significant barriers preventing use of the GBLE, we also did not find much enthusiasm to make use of it. As in previous studies in Chapter 5 and this chapter, students found the GBLE mostly useful for other learners, but not for themselves. The social interaction features did not lead to wide use, and were not able to facilitate a meaningful exchange of learning insights among learners. The forming of groups, and the combination of intergroup competition with intragroup collaboration, nor the elements of points, badges, and a leaderboard led to sufficient motivation for learners to use and sustain use of the GBLE. The effort of writing out goals, methods, and plans, was perceived as too much for most students – especially when also keeping track of them using different tools or in a non-digital way. For some students, this effort came on top of the already high amount of effort required to study altogether. Another group of students did not find they needed the support offered by the GBLE or simply forgot about it being available in spite of repeated reminders.

Although we found no indications of problems with the explicit system prompts and otherwise high amount of learner control, it remains unclear whether learners were able to use it in a productive way. Perhaps additional instructions and scaffolds, as were present in the tool presented in Chapter 5, could have worked towards learning how to use the GBLE in a step-by-step way. For example, the feature regarding methods of learning seemed more difficult to use productively, and perhaps offering a few pre-made learning strategies could have improved its use. Moreover, additional cues within the GBLE but also within the classroom, may have helped learners to use the GBLE more regularly and more productively. Altogether, in the present study our limited cues were insufficient to initiate use of the GBLE, as were the mechanisms within the GBLE to sustain it.

4. Discussion

The aim of this chapter is to identify and formulate design knowledge drawn from designing game-based metacognitive training and evaluating these designs in real-world educational contexts. On the one hand, we tried to disentangle the design of such GBLEs by specifying which design principles were combined into a coherent design and how this design was implemented as a specific prototype. On the other hand, we tried to shed light on how these GBLEs, as a prototyped intervention, were perceived and used by learners and whether learning and metacognition were affected.

However, we did not attempt to link together these two perspectives: we did not disentangle the evaluation findings in terms of each of the underlying design principles. We also do not want, at this point, to make strict claims about what does work and what does not work. To our knowledge, there is no rigorous method available to analyze such findings across multiple designs and studies on a limited scale in time and number of participants. Moreover, such a method would need to take into account all relevant differences in implementations and evaluation contexts, as well as account for the interactions between design principles. Even if such a method were available, we doubt whether it could yield any meaningful and helpful recommendations beyond a specific implementation within a specific context.

We did strive to sample the design space with different configurations for the dimensions of the DFM-GBL. For each design experiment, a design dashboard visualization is shown in Figure 6.9, indicating how the design is positioned within the design space described by the design framework. It can be clearly seen that all these instances implement a domain-general and detached approach, leaving further room for domain-specific and embedded design experiments. Also, most of these instances represent individual rather than social gameplay. Thus, while most dimensions varied between these four design experiments, there are also dimensions that strongly coincide.

We do find value in both parts of our approach: the principles represent a more transferrable type of design knowledge than the design-as-a-whole, while the evaluation results represent valuable insights on how each design-as-a-whole is used and perceived in practice. There are many useful insights that can be taken from these case studies and that may help other designers and researchers and we do want to share these insights in a meaningful way. We first present our design recommendations for the different dimensions of the DFM-GBL stemming from the case studies presented in this chapter. For the sake of brevity we will do so in a manner-of-fact way. We then proceed to discuss in more detail two main issues that many of our findings can be traced back to: the integration of metacognitive training with gameplay and domain-generality of game-based metacognitive training. We conclude the chapter with a review of our approach and implications for future research.

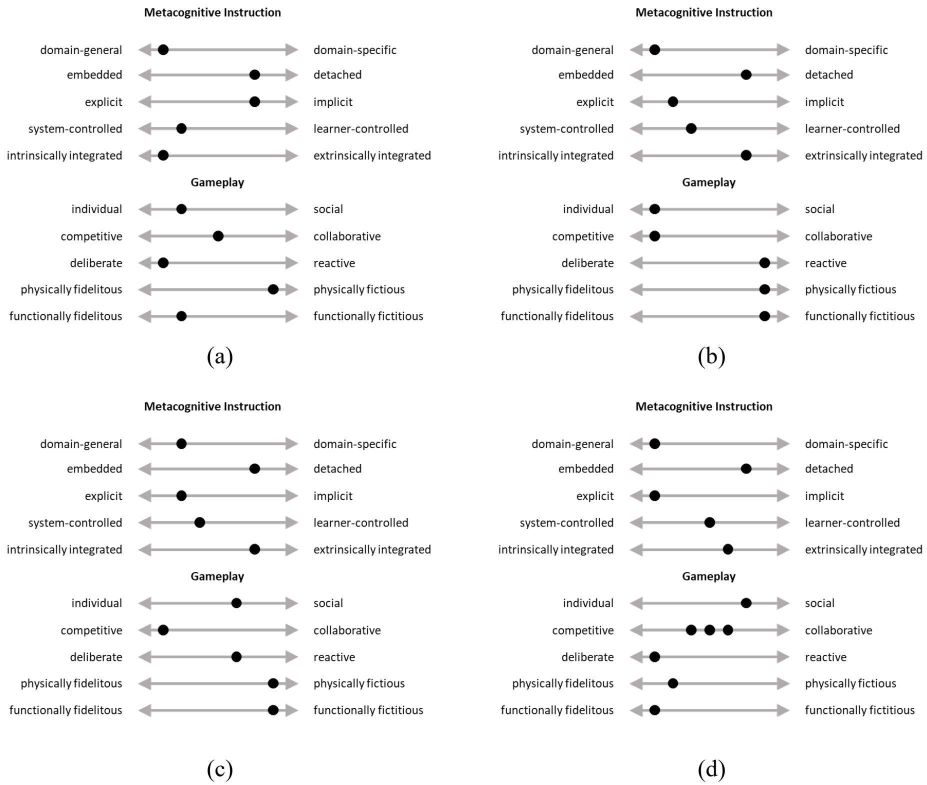


Figure 6.9: Overview of design dimension dashboard visualizations, one for each design experiment: (a) MeCO, (b) L2C-1, (c) L2C-2, and (d) ML-2.

4.1 Recommendations for Designing Game-Based Metacognitive Training

In addition to the findings of each design experiment, as discussed in the respective results and conclusion sections, we will here provide our recommendations for designing game-based metacognitive training in terms of the dimensions of the DFM-GBL (see Table 6.7).

Table 6.7:Recommendations for designing game-based metacognitive training (table continues on the following pages)..

Design Dimensions for Instruction
(1) To what extent is metacognitive instruction domain-general or domain-specific?
Make metacognitive support as relevant as possible to ongoing domain-specific learning – for example by suggesting strategies that are specifically relevant for current learning goals and activities.
When adopting a domain-general approach, allow users to enter their own learning goals and activities: this allows users to connect domain-general support to ongoing domain-specific learning. Furthermore, make sure that additional support helps learners to make the far transfer from metacognitive training to real-world learning.
The mechanisms to promote transfer of metacognition to learning should be explicit and should be presented apart from gameplay to emphasize their different role
(2) To what extent is metacognitive instruction embedded within or detached from domain-specific content?
When domain-specific learning content is also taught within the GBLE, embed metacognitive training within this content of the GBLE: this makes the transfer easier and makes the support more relevant.
When it is not possible to embed metacognitive support in domain-specific learning content, ensure that learners are aware of how the detached support applies to and is relevant for ongoing real-world learning.
(3) To what extent is the metacognitive instruction explicit or implicit about what a learner needs to do?
Inform users explicitly, beforehand, about the purpose and potential benefit of using the GBLE as this increases interest as well as the potential of transfer of metacognition to learning.
Explicitly address learning in terms of the goals, activities, and strategies it involves. This can also be done in a summary after an episode of gameplay.
Explicitly instruct and encourage learners to make use of the available metacognitive support features within the GBLE. Implement support features that cue the use of the available support.
Consider learners' experience with learning and vary explicit instruction and implicit support accordingly.
(4) To what extent is metacognitive instruction controlled by the system or by the learner?
Take into account the amount of effort involved in student control of the metacognitive support. Avoid superfluous effort and hard thinking without discernable benefits.
System control works well on specific resource management tasks such as timekeeping. A higher amount of system control needs to be combined with adaptiveness to learner needs and relevance of the provided support.

Table 6.7 (continued).

(5) To what extent is metacognitive instruction intrinsically integrated with the gameplay activities?

When intrinsically integrating metacognitive training with gameplay, avoid relying too much on metaphor and analogy to link in-game interactions and events to real-world learning: the connection will likely be too implicit to be effective.

When extrinsically integrating metacognition with gameplay, be careful about the balance between time spent on game activities and on learning activities. Relate the gameplay loop to learning activities to benefit motivation as well as learning.

Extrinsic integration risks disengagement as playing and learning become separated. These issues may be more prominent with detached and domain-general designs and less relevant when using an embedded and domain-specific design.

Design Dimensions for Gameplay

(1) To what extent does the game involve social or individual interactions?

Make sure that learners can relate metacognitive training to their own individual learning.

Incorporate social interactions within the GBLE as these can work to promote motivation as well as metacognition.

Explain and point out the use of social interactions within the GBLE and how these contribute to learning to encourage learners to make use of these.

(2) To what extent does the game involve competition or collaboration between agents?

Avoid competition between learners on indicators of learning or metacognition: such performance-based competition is likely to disengage all but the high-ranking learners. Instead, seek for indicators of effort, novelty, and exploration of learning.

Collaboration with virtual characters worked well for motivation and could be used to promote metacognition within gameplay.

(3) To what extent does the game involve deliberate or reactive responses from the player?

Choose a deliberate type of gameplay that avoids time pressure and promotes thinking and reflection – in particular when striving to integrate metacognition with the gameplay. This allows players to reflect on choices and speculate on alternative outcomes.

Alternate between metacognitive activities and gameplay activities to allow learners to engage in these activities from a different cognitive stance. Gameplay can then also involve reactive elements.

Consider the value of replay: players can be interested in exploring different choices and corresponding outcomes on a subsequent playthrough – which could be an effective mechanism for promoting metacognition through gameplay.

Table 6.7 (continued).

(4) To what extent is the game fidelitous to or fictitious about representing the target learning situation?
The more fidelitous the GBLE is to real-world learning, the easier it is for learners to connect metacognition to learning.
Carefully consider which characters and interactions are used to support transfer of metacognition to learning as seemingly subtle design choices may have a big impact on effectiveness.
Avoid too much humor or fantasy around the interactions that are critical to transfer of metacognition to learning.

4.2 Integrating Metacognitive Training with Gameplay

Research of domain-specific GBL recommends intrinsic integration of learning content with gameplay, however, our design experiments indicate that intrinsic integration of metacognitive training with gameplay is not similarly effective.

In Design Experiment #1 we intrinsically integrated metacognitive instruction with gameplay. We aligned goals and mechanics with metacognitive training objectives, but in particular made use of the interactive narrative, and its setting, characters, and events. We learned that learners struggled to make any connection to their ongoing real-world learning. Thus, while we aligned gameplay with metacognitive activities, these activities did not foster a transfer to real-world learning. The prompts that were implemented to promote this transfer were ineffective, as the prompts themselves were embedded in the narrative through the robot character. We learned that the mechanisms to promote transfer of metacognition to learning should be *more explicit and less fictitious*, and should be *presented apart from gameplay to emphasize their different role*.

We have to consider the possibility that our findings were not due to intrinsic integration in general, but merely specific to our particular design and implementation. Perhaps a less fictitious setting, such as a university with various classes, professors, and students, could help learners to make the connection more easily, while retaining the appeal of the current game design. Or perhaps a better integration of game mechanics with metacognitive training could be achieved. For example, metacognitive activities, such as setting a goal or applying a strategy, could contribute to in-game abilities and scoring. However, previous research discusses similar issues when integrating such reflective activities with gameplay (Sabourin et al., 2013; Verpoorten et al., 2014). Correspondingly, approaches that more explicitly differentiate between gameplay and reflection thereupon have been shown to be effective (Castronovo et al., 2018; Fiorella & Mayer, 2012). This leads us to wonder *whether intrinsic integration of metacognitive training with gameplay is possible or even desirable*.

In Design Experiment #1, where metacognition and gameplay were presented at the same time and without differentiation, we struggled with facilitating transfer. In Design Experiments #2 and #3, the learning part of the GBLE required deliberate interaction (e.g., choosing and setting learning goals and strategies, planning and conducting learning activities) while the gameplay part required reactive interaction (e.g., dodging and attacking enemies). Furthermore, here metacognition and gameplay were presented in different screens and, crucially, at different times. Learners could focus on play, or on learning, but not both at the same time.

We learned that, due to their different focus of learner attention, *such a disconnection between learning and playing may be necessary to facilitate game-based metacognitive training*. As metacognition requires a learner to inspect and adjust their own learning, it may be useful to reflect this different focus of attention in the design of the GBLE. The complexity of integrating metacognitive support with gameplay is to combine the "doing" associated with experiential learning of GBL with the "thinking" associated with metacognition. The stance adopted when learning, playing, problem-solving, could be inherently different from the stance adopted when monitoring, strategizing and reflecting (Martinez-Garza & Clark, 2017). In this sense, metacognition is at odds with experiential learning and requires an extra step beyond the context of the game – "breaking the fourth wall", if you will – for real-world learning to be affected.

4.3 Domain-General and Detached Metacognitive Training

While domain-specific and embedded metacognitive training may be easier for learners to apply, domain-general training and detached metacognitive training has the potential benefit of being applicable across a large range of learning topics and contexts and correspondingly offering increased opportunities to practice and improve (Osman & Hannafin, 1992; Schraw, 1998; Veenman et al., 2006). The domain-general and detached approach, however, greatly complicates the design of both instruction and gameplay.

Our design experiments demonstrate the complexities of facilitating this far transfer of general metacognitive knowledge and skills from current GBL to future real-world learning situations. In Design Experiment #1, learners did not link gameplay to ongoing real-world learning. In Design Experiment #2 and #3, we allowed learners to self-explicate their goals, plans, strategies, and other aspects of learning and, as such, encouraged them to connect ongoing learning to our detached metacognitive support. When combined with partially domain-specific learning strategies, as introduced in the third experiments, the results show that most learners were able to make this connection in a meaningful way. In Design Experiment #4, we did not offer any predefined strategies, and participants specifically suggested including them. Together, the design experiments thus hint towards the need for at least some domain-specific connection of metacognitive training to learning. Further research could focus on identifying ways in which a domain-general approach can connect to domain-specific learning, at different levels of learning. Such connections could, for example, be made through user-entered content, through fostering peer discussion of learning approaches, and through facilitating peer feedback. The challenge is to *retain the benefits of domain-general metacognitive training while reducing the effort of far transfer*.

We found that the domain-general approach also has greatly complicated the game design. No assumptions can be made about the content of learning, nor about the progress or performance of the learner. A *lack of such a performance measure* – of either domain-specific learning (e.g., do the learners do well or not, do they need help, and if so, what kind of help), or of metacognition (e.g., do the learners have increased metacognitive knowledge, do they employ metacognitive skills, is their learning behavior improved) – *makes it hard to reward any performance achieved in learner activities*. We experimented with other incentive structures that reward the effort of trying out new strategies (Design Experiments #2 and #3) or the effort of performing metacognitive activities (Design Experiment #4), but without clear success.

For future research, it would be interesting to combine such approaches with *efforts to automatically judge the quality of the goals, methods, plans, and other self-explications of learning as a measure of metacognitive performance* (cf. Snow, McNamara, et al., 2015). Such an approach could identify different levels of metacognition and adaptively link this to an appropriate level and type of metacognitive support (cf. Steiner, Kickmeier-Rust, Mattheiss, Göbel, & Albert, 2012).

4.4 Conclusions

In this chapter we have discussed four design experiments. We presented the design principles with which our designs of game-based metacognitive training were constructed, presented the rationale of each design in terms of these design principles and in terms of DFM-GBL, and presented the evaluation of each designed prototype in real-world educational settings. We sampled the design space exactly where, on the central dimensions, little information on GBLE-design was previously available and investigated GBLEs that offer not embedded (but detached) and not domain-specific (but domain-general) metacognitive training.

The design experiments identified that the complexity of designing GBLEs for metacognition centers around the three dimensions of the DFM-GBL that describe how learning content, game content, and metacognitive instruction interrelate: whether metacognition is embedded in (or detached from) learning content, whether metacognition is domain-specific (or domain-general), and whether metacognition is intrinsic (or extrinsic) to the gameplay.

Consider for example the use of prompts to encourage learners to make the connection between metacognitive activities within the GBLE and ongoing learning outside of the GBLE. The prompts that were implemented in MeCo to promote this transfer were ineffective, as the prompts themselves were embedded in the narrative through the robot character. We now think that *the mechanisms to promote transfer of metacognition to learning should be more explicit and less fictitious, and should* *be presented apart from gameplay to emphasize their different role*. For example, after completing a part of the game, a feedback screen could be presented, with accompanying transfer prompts, to let learner step back from the game and reflect upon the relevant insights for their own learning. Such design decisions thus cut across the central dimensions of the DFM-GBL, and influence subsequent design choices within other dimensions.

Consider, as another example, our attempts to combine metacognition with gameplay in different ways. Previous work on metacognitive instruction recommends that metacognitive instruction be embedded in learning content. Previous work on GBL recommends embedding learning content with gameplay. However, our design experiments – an interdisciplinary attempt to combine insights from these and other fields – demonstrate that *combining learning content, gameplay, and metacognition is complicated at best and undesirable at worst*. Adopting a detached and domain-general approach, we found that learners find it hard to bridge the gap between GBLE and ongoing learning; in particular when metacognitive instruction and support are integrated within gameplay and part of a fictitious narrative. A non-integrated approach, where gameplay and metacognitive activities are alternated or separated, seemed to work better and accommodates the different cognitive stances associated with playing and learning.

In line with the proposition that in GBL learners alternate between a playing stance (a state of mind aimed at optimizing in-game performance) and a learning stance (a state of mind aimed at optimizing understanding of the game and the relationships it portrays) (Martinez-Garza & Clark, 2017), we conjecture that learning may additionally involve a metacognitive stance (a state of mind aimed at optimizing learning itself). Perhaps all our design experiments were, in hindsight, aimed at resolving this three-way relationship that is reflected in the three central dimensions of the DFM-GBL.

Where the DFM-GBL initially provided only the relevant design dimensions, we added more detail by formulating design principles and providing design recommendations based on our designs and design experiments. However, we found that it is hard to engage learners with metacognitive instruction and support through GBL when they perceive a gap between what they are doing for their ongoing learning and what the GBLE requires and offers. Further research could focus on identifying ways in which a domain-general approach can connect to domain-specific learning, at different levels of learning. Such connections could, for example, be made through user-entered content, through fostering peer discussion of learning approaches, and through facilitating peer feedback. Future design can take advantage of the DFM-GBL and design recommendations to design better GBLEs for metacognitive outcomes. Future research should focus on resolving the complexities of combining learning, gameplay, and metacognition. With combined effort, and taking advantage from our learnings, future design and future research may find more sophisticated ways of improving metacognition through GBL.

chapter seven

General Discussion

1. Introduction

At the start of this dissertation we shared the story of Alex, a student who had not learned how to self-regulate his learning by using their metacognitive knowledge and skills. Unfortunately, nothing and no one in the initial three-and-a-half years of studying had caused him to become aware of this problem. And nothing had been provided to help him to address this problem.

We propose that GBLEs can help students, such as Alex, to develop their metacognition in an interactive and engaging way. In this dissertation, we describe our research into the design of such *game-based metacognitive training*. Of course, we do not aim to help specifically Alex or Alex alone. We strive to investigate the design of interventions that would appeal to and be useful for a wider range of students in higher education. We also strive to inform other designers and researchers with the same or similar ambitions. Beyond the design of a specific tool, we are particularly interested in the underlying design knowledge that would enable us – and would enable potential future designers and researchers – to design and develop such tools more effectively. In other words, we want to help students like Alex, and we want to help designers and researchers who want to help students like Alex.

In this final chapter, we reflect upon this work. We first present a brief rationale and overview of our work and, subsequently, its key findings and implications. We then present two outlooks towards further development of our ideas in future research: on game-based metacognitive training and on educational design research. We conclude with our outlook for higher education from the perspective of metacognition and self-regulation.

2. Key Insights and Implications

In this section we reiterate the rationale and overview of the research in this dissertation and then proceed to present the key findings and implications of this work.

2.1 Rationale and Overview

We define metacognition as a learner's understanding of how knowledge is constructed through learning, and the repertoire of strategies, tactics, and monitoring processes that aid learning (Flavell, 1979; Kuhn, 2000; Schraw & Moshman, 1995; Veenman et al., 2006; Winne & Hadwin, 1998). As such, we regard metacognition within an educational context and in relation to the self-regulated learning process. The metacognitive knowledge (e.g., about oneself, learning, strategies, etc.) and metacognitive skills (e.g., goal-setting, planning, reflection, etc.) of a learner affect learning through monitoring (i.e., assessing learning against expectations) and regulation (i.e., adjusting learning as deemed necessary) (Nelson & Narens, 1990, 1994; Schraw & Moshman, 1995; Zimmerman & Campillo, 2003).

As metacognition is one of the most salient determinants of efficient and effective learning, it is important to ensure that learners develop adequate metacognitive knowledge and skills. Within higher education, metacognitive knowledge and skills are often implicitly expected of learners, but seldom explicitly and structurally taught within study programs. Generally, the focus of a study program is on its subject matter rather than on how this subject matter is best learned. However, developing metacognition improves students' ability to detect and address issues that inevitably occur during learning. In addition to teaching students' specific knowledge and skills, metacognitive training is about teaching them how to acquire new knowledge in an effective and efficient way. Providing learners with metacognitive training is a very effective way of improving their current and future learning skills and, in turn, their learning performance.

Metacognitive training, consisting of metacognitive instruction (e.g., direct instruction of learning strategies) and metacognitive support (e.g., cues to use a learning strategy), can augment such subject matter training to help learners improve their learning performance in the long term. Within higher education, metacognition needs to be trained (i) in an *active* way to enable learners to develop the required knowledge as well as produce the desired behaviors, (ii) in an *engaging* way to motivate learners to initiate and sustain an effort that comes on top of regular studying effort and only yields over time, and (iii) in a *self-contained* way that students can make use of regardless of whether a teacher is available.

One medium in particular meets all of these requirements: GBL is best known for its qualities of offering active and interactive training that engage learners with the training content within a self-contained GBLE. The challenge and fantasy that games can offer appeals to a broad range of people and can be effectively used to practice and improve previously learned knowledge and skills, as well as to acquire new ones. Moreover, games can support a wide range of instructional activities that encompass both instruction and support. While it is clear that GBL can help learners attain certain types of learning outcomes, current research lacks the design knowledge to effectively construct GBLEs that train metacognition in learners (Hacker, 2017; Ke, 2016; Sitzmann, 2011; Wouters et al., 2013).

The main research question in this dissertation thus focuses on how we can design effective GBLEs to improve metacognition in learners in higher education. In particular, we want to (i) *gather and synthesize design knowledge*, across different disciplines and from existent and new research, to further the understanding of the design of GBLEs for metacognition, and (ii) *apply and evaluate design knowledge* in real-world educational settings, through the conceptualization and construction of prototypes, and by collecting insights from students using them.

In the first part of this dissertation, during the *Analysis & Exploration* phase of research, we synthesized current research and organized understanding of the design of GBLEs with the purpose of enhancing metacognition. We conducted a qualitative literature review to identify terminology, main objectives, mechanisms, and evaluation outcomes. Based on a selection of example designs from the review study, and through a formative evaluation with field experts, we developed a design framework that identifies the salient design dimensions of game-based metacognitive training.

In the second part of this dissertation, during the *Design & Construction* and *Evaluation & Reflection* phases of research, we formulated and verified insights about how the design of a GBLE affects learners and learning. We applied the design framework through various designs and design implementations in the form of prototypes. With these prototypes, we conducted exploratory and confirmatory evaluations through which we developed design knowledge that complements the design framework.

In the next section, we will discuss our key findings and implications from this work.

2.2 Key Findings and Implications

Our qualitative review of the state-of-the-art in GBL of metacognition indicates that knowledge within this interdisciplinary area of research consists mostly of case-by-case findings. The limited ways in which GBLE-designs and underlying design choices can be compared stands in the way of advancing insights. To advance insights on promoting metacognition through GBL from case-by-case findings towards intermediate-level design knowledge requires more specificity (clear, shared, and practical view on metacognition as well as GBL), enabling increased comparability (ability to compare different approaches and systems), resulting in improved transferability (transfer of knowledge from specific cases towards other, current and future, designs).

We first discuss the present interdisciplinary state of the art, guided by three types of work. We then proceed to discuss our contributions in terms of the design framework and corresponding design knowledge.

Interdisciplinary State of the Art

The research in this dissertation is interdisciplinary in nature, as it combines insights from and provides contributions to multiple areas of research such as instructional design, educational psychology, game-based learning, serious games, and design science. To characterize the current state-of-the-art in design knowledge for designing game-based metacognitive training, consider the following three kinds of work that could provide such design knowledge.

First, there is work that discusses *instruction and support of metacognition* in general (i.e., regardless of the delivery method). For example, metacognitive strategies can be taught through direct instruction in the classroom (Hartman, 2001a; Zepeda, Hlutkowsky, Partika, & Nokes-Malach, 2018; Zepeda et al., 2015) and metacognitive strategy use can be supported within digital environments through cues and prompts (Bannert & Mengelkamp, 2013; Merriënboer & Bruin, 2019). There is ample work of this type (Derry & Murphy, 1986; Lin, 2001; Osman & Hannafin, 1992; Veenman & Spaans, 2005; Veenman et al., 2006), however, to translate insights from such work into meaningful design knowledge for GBLEs is not straightforward and requires intricate understanding of both worlds.

Second, there is work that discusses *learning with games and through gameplay* in a somewhat generic way. It is generally well-understood how skills can be practiced and improved through play (Graesser, 2017), as is evident in the many examples of applying GBL to learning operations in mathematics or mechanics in physics. Furthermore, there is ample research on the most important components and mechanisms involved in GBL (Plass et al., 2015, 2019; Slussareff et al., 2016) and on how instructional support within GBLEs can further enhance learning performance (Wouters & Van Oostendorp, 2013, 2017). However, it is not yet clear how GBL can address more complex and higher-order learning outcomes (Crocco, Offenholley, & Hernandez, 2016; Graesser, 2017; Hung & Van Eck, 2010; J. Lee & Choi, 2017; Young et al., 2012). While some of this type work addresses the issue of how metacognition affects experiential learning through interaction and play (Azevedo et al., 2012; Cloude, Taub, Lester, & Azevedo, 2019; Hacker, 2017; Liu & Liu, 2020), our interest is in how GBL can positively affect metacognition. Altogether, from work of this type, not all insights that apply to training domain-specific learning content will directly translate to training metacognition.

Third, there is work that specifically discusses *training metacognition through game-based learning*. Our review provides an overview of this type of work. Most of this type of work discusses a specific design, presents an evaluation of an intervention that implements this design, and then reports on its effects on learners, learning, and metacognition. The underlying design knowledge and the working mechanisms that are relevant to inform future designs, are often not clear from this work. Further, this type of work predominantly focuses on an approach of embedding metacognitive training within domain-specific content (e.g., language learning, health care, mathematics physics) and limits the role of metacognition to improve current learning (Zumbach, Rammerstorfer, & Deibl, 2020). The few examples that do not make assumptions about the domain of learning address only a very specific part of metacognition (e.g., cognitive biases: Bessarabova et al., 2016) or address a broader concept encompassing metacognition (e.g., cognitive adaptability: Gallagher & Prestwich, 2013). This implies that current research does not adequately reflect the potential design space of GBLEs for promoting metacognition as a whole with the aim of improving current *and* future learning.

Work that addresses metacognitive training with GBL and attempts to formulate more generically applicable design recommendations on how to foster metacognition through GBL is rather scarce. Various reviews of GBL have proposed that further research is conducted into how games can address higher-order learning outcomes in general and metacognition in particular (Graesser, 2017; Ke, 2016; Sitzmann, 2011). Previous research has provided some general ideas about the role that metacognition plays in GBL (Hacker, 2017), and has identified challenges and future directions for enhancing self-regulated learning and metacognition through games (Nietfeld & Shores, 2011). Furthermore, and more specifically, Mayer (2016) has suggested a number of principles for designing games to promote metacognition within the domain of science, technology, engineering, and mathematics.

For research on GBL for metacognition to advance, we need to develop more formalized ways for researchers to communicate about the design space, the designs, the underlying design choices, in relation to implementations and their effects on learners and learning. Recent work further supports the idea *that* GBL can support and improve metacognitive awareness, self-regulation and reflection (Betts & Rothschild, 2020; Ouellette, 2019; Ricker & Richert, 2021; Taub, Azevedo, Bradbury, & Mudrick, 2020). Our work is, to our knowledge, the first comprehensive investigation of *how* GBL could affect metacognition through the various elements of its design.

Design Framework

The three kinds of work we identified characterize the interdisciplinary nature of our own work: while our emphasis is on identifying and elaborating design knowledge of the third kind, we must acknowledge and incorporate previous work of the first and second kinds. One of our key contributions is the development of a design framework that brings together the concepts involved in designing game-based metacognitive training, as well as the relationships between these concepts. This design framework fulfills five different roles.

First, the design framework provides definitions and categorizations that should help to discuss approaches, designs, and mechanisms in a more coherent way. In other words, the suggested vocabulary contributes to the specificity with which design knowledge can be communicated across different disciplines and fields. Furthermore, our work provides a categorization of different metacognitive mechanism types for GBL and of different approaches to integrating metacognitive instruction and support with gameplay.

Second, the design framework can be considered as a map of the design space that helps designers to navigate this space when designing a GBLE to promote metacognition. The framework indicates the most salient dimensions of designing instruction and gameplay to facilitate metacognitive training for which design choices need to be made. While it is not always clear how an informed design choice can be made with current knowledge, at least is now more clear which kind of design choices must be made. As such, the design framework also helps to bridge an interdisciplinary gap.

Third, the design framework can be considered as a means of organizing design knowledge in a structured way. Design recommendations, principles, and guidelines can be formulated for specific aspects of the design as indicated by the dimensions, rather than for the design as a whole, thereby reducing design complexity. As such, the framework aids designers in making design choices.

Fourth, the design framework can be considered as a means of comparing and contrasting designs in the search for effective approaches and mechanisms. As demonstrated by the comparisons utilized in developing and evaluating the design framework, its dimensions allow the description of different interventions in a similar way. Designs of GBLEs for metacognition can be specified in a more structured way, such that similarities and differences can be compared more easily. As such, we contribute to improving comparability and transferability of design knowledge in this specific area of design.

Fifth, the design framework can be regarded as the start of a research agenda. The design dimensions represent the relevant areas of the design space and for each dimension the current insights as well as research gaps can be identified. Our overview already indicates multiple gaps that invite future research. Design knowledge from creating and evaluating GBLEs that sample areas of the design space can, as it becomes available, be formulated for the different dimensions to advance insights towards a comprehensive view of the design space. In this role, the design framework provides a structure that can encourage future work and accommodate future insights.

Design Knowledge

Our subsequent contributions to design knowledge augment the descriptive design framework with more prescriptive design recommendations. We designed, developed, and evaluated prototypes that implement various combinations of design principles within the dimensions of the framework. The corresponding design experiments focused on the role the different design principles fulfil within the design of the prototype: to what extent the elements of the design are incorporated to facilitate learning (e.g., a digital card explaining a learning strategy), to facilitate motivation (e.g., an achievement badge to reward a metacognitive activity), or to do both (e.g., a metacognitive question asked by a robot). As such, our investigations have focused on linking design choices to elements and mechanisms in the design to the perceptions and effects as they occur with learners who make use of these tools.

The aforementioned three types of work are paralleled in the types of design knowledge we identified within the dimensions of the design framework. We advanced insights within the instructional dimensions, gameplay dimensions, and on how instruction and gameplay can be combined, and we will address these three perspectives next.

Regarding the *instructional design*, we found that a three-way relationship between metacognitive training content, domain-specific learning content, and gameplay determines to a large extent the efficacy of game-based metacognitive training. While the dominant approach in previous work is to embed metacognitive training within domain-specific training content and gameplay, our work mainly explores an alternative approach of detached and domain-general metacognitive training. While the former type of training is generally more effective, this latter type of training is relevant to investigate given that it applies to a wider range of subject matters and educational contexts (Carpenter, Sherman, Seth, & Fleming, 2019; Eccles & Feltovich, 2008; Osman & Hannafin, 1992; Schraw, 1998). As such, this approach is very suitable within higher education, which typically involves learners involved in multiple topics, courses, and projects, in parallel and over several years of learning.

Our findings indicate that detached and domain-general metacognitive training can improve metacognition and positively impact learning. We conceptually developed the mechanism of self-explication to articulate otherwise implicit beliefs about learning. Using a digital tool, learners can identify such beliefs about learning and examine them for merit throughout the phases of their own ongoing learning process. Self-explication has the added benefit of having learners add their own domain-specific goals, plans, strategies, and evaluations to otherwise domain-general support. As such, domain-general training becomes concrete enough to affect ongoing domain-specific learning. Our findings further indicate that such metacognitive training must be explicit about what is expected of learners and must contain additional mechanisms that support transfer of metacognitive training within the GBLE to real-world learning within or outside of it.

Regarding the *gameplay design*, we found that the instruction and transfer of domain-general metacognition through GBL is complex to achieve.

One of the objectives of using GBL to promote metacognition is to make such training more attractive for learners to begin with and to sustain over an extended period of time. However, our findings indicate that precisely those learners who could benefit most from available metacognitive training, are likely to not make use of such support. This effect was found when examining a non-game-based intervention and could not be found when examining game-based interventions.

Learners often experience metacognitive training as extraneous to their domain-specific studying efforts – especially when training is not embedded in domain-specific training content. Our findings corroborate the findings of Clarebout et al. (2013) that learners make metacognitive judgments about whether using available metacognitive instruction and support seems worth their effort. This effect was much reduced when the GBLE was embedded in and supported by regular sessions with additional instructions to encourage effective use. This implies that the use of metacognitive support tools needs to be encouraged and cued within the context of ongoing learning (e.g., within classes or through other meetings) before learners develop a habit of self-initiating metacognitive processing.

When regarding the role of gameplay to help learners to develop and retain the desired behavior, the combination of individual and social interactions, as well as collaborative play, seems most viable to help make this connection. The learners in our studies repeatedly asked for features supporting this, and recent work further elaborates social and collaborative play to foster metacognition (Betts & Rothschild, 2020; Fishovitz, Crawford, & Kloepper, 2020; Novak, 2017).

When regarding the role of gameplay to foster metacognition in learners, deliberate and discrete gameplay lends itself better to teaching metacognition than reactive and continuous gameplay, if only for allowing learners to overthink their choices before enacting them. Gameplay that is fidelitous to the setting of real-world learning makes it easier for learners to make the connection between in-game metacognitive training content and real-world learning.

Regarding the *combination of instruction and gameplay*, we found that the type of integration of metacognitive training with gameplay strongly affects how the gameplay dimensions must be viewed.

When metacognitive training is integrated with the gameplay, it becomes harder for learners to distinguish between what is specific to the game and what is relevant to transfer to real-world learning settings. For example, embedding metacognitive prompts within the setting and narrative of the game turned out to be detrimental to its effectiveness.

When metacognitive training is not integrated with the gameplay, and no domain-specific learning content is involved, the remaining function of gameplay is motivation. In this approach, there needs to be some alternative connection between training and gameplay lest the two components become completely separate – for example by interweaving related but distinct elements of the GBLE.

An overview of current design knowledge in terms of the aforementioned three kinds of work and in relation to the dimensions of the design framework is included in Appendix C.

3. On Game-Based Metacognitive Training

In this section we synthesize our work towards two outcomes. First, we present the beginnings of a design process for game-based metacognitive training that ties together our design framework, design principles, and overall recommendations in a coherent and comprehensive way. Second, we present our ideas of a theoretical model that integrates previous work from different disciplines and could inform future work on game-based metacognitive training. With these two outcomes we hope to provide a basis for future researchers and designers to build upon.

3.1 Towards a Design Process for Game-Based Metacognitive Training

While we created a design framework and formulated design principles and guidelines, we did not yet provide an integrated method to apply such design knowledge to the design of game-based metacognitive training. Based on our research, we now present a design process that incorporates the different types of design knowledge as outlined throughout this dissertation.

The three steps of this design process are (1) identifying and defining the desired outcomes, (2) configuring the primary dimensions of the design framework, and (3) configuring the remaining dimensions of the design framework. This three-step design process shown in Figure 7.1 with the key options at each step and the relationship with the design framework and design principles. While each of these steps seems somewhat straightforward, let us describe in some more detail how together these steps combine the provided design knowledge into a more comprehensive design process.

Step 1: identifying and defining the desired outcomes

When designing a GBLE for metacognitive training, we recommend beginning with the end in mind. It must be clear for which metacognitive objectives the GBLE is being designed in order for the design to be able to be effective. This may seem obvious, however, we found that many previous studies did not specifically formulate such outcomes. We recommend that well-defined metacognitive objectives are formulated in terms of the expected effects on learners and their learning in a testable way. For example, a desired outcome could be that learners know three particular learning strategies (i.e., the goal is to increase metacognitive knowledge of strategies) and that they apply them during their studying effort (i.e., an observed increase in use of these strategies is a testable indicator of success).

When selecting and formulating such outcomes, we recommend taking into account the differences in type of metacognition (e.g., knowledge or skills), the role of metacognition (e.g., support metacognition to enhance current learning or improve metacognition itself to enhance future learning), and the domain-generality of metacognition (e.g., specific to current domain or general across different domains). These three aspects strongly affect the design. For example, in the case of domain-general metacognitive training, learners will need support to facilitate transferring metacognitive training to ongoing learning. Or, as another example, when training metacognitive knowledge an instructional approach that is explicit and directive is preferred whereas when training metacognitive skills, it is recommend to support practice with cues, prompts, and feedback.

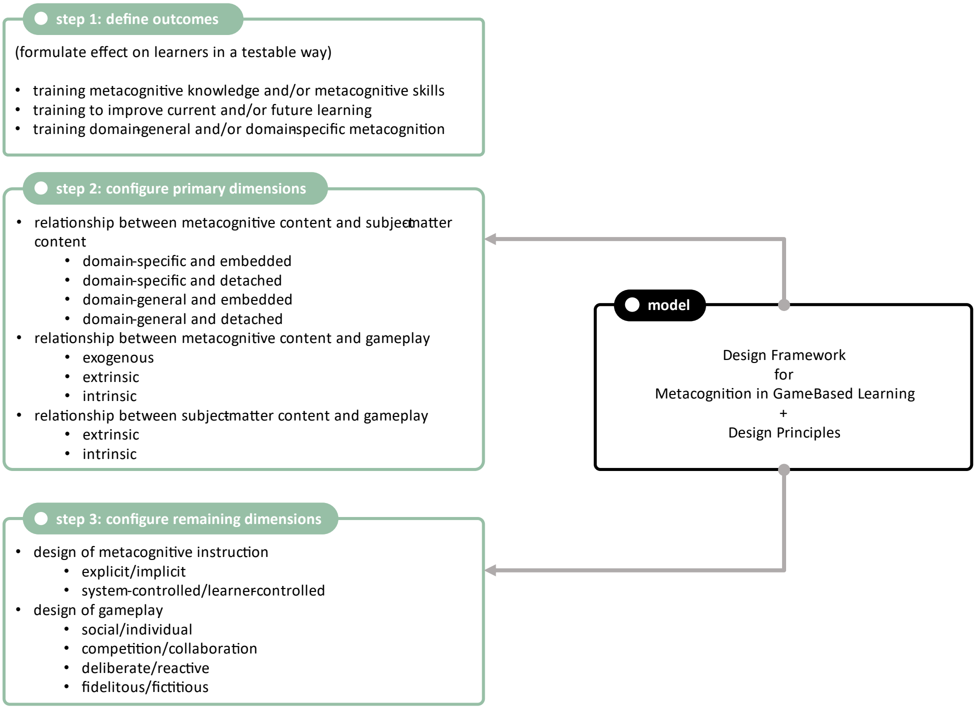


Figure 7.1: Overview of design process steps, options at each step, and its relation to the provided design framework and design principles.

Having well-defined outcomes allows decisions to be made about when metacognitive instruction and support are of added value and when they are no longer necessary. For example, if a learner is clearly aware of a particular strategy, and able to demonstrate its use, further instruction is unhelpful. Continuing to offer support may even be detrimental, as it prohibits learners from practicing and demonstrating self-initiated and self-regulated strategy use. Perhaps metacognitive instruction should now proceed with training a different strategy, or perhaps metacognitive support should now fade to occasionally cueing learners to monitor strategy use. Well-defined outcomes support a designer in making such design decisions and to select the appropriate mechanisms for specific outcomes. Moreover, well-defined outcomes support adaptive designs that use such outcomes to determine what level and type of support is necessary for a particular learner over time (cf. Carpenter et al., 2019; Kautzmann & Jaques, 2019; Pannese, Morosini, Moore, & Pammer, 2012; Steiner et al., 2012).

Step 2: configuring the primary dimensions of the framework

The primary dimensions of the framework describe the three-way relationship between metacognitive learning content, subject matter learning content, metacognitive content, and gameplay content. For each dimension, the design principles offer a basis for making design decisions.

The relationship between gameplay and subject matter content is beyond our scope of designing game-based *metacognitive* training, and we refer to ample available literature on intrinsic integration (cf. Echeverría, Barrios, Nussbaum, Améstica, & Leclerc, 2012; Habgood & Ainsworth, 2011; Ke, 2016) and alignment (cf. Amory, 2007; Arnab et al., 2015; Shelton & Scoresby, 2011) of learning and gameplay.

First, we consider the relationships between metacognitive and subject matter content in relation to the choice for domain-specific or domain-general metacognitive objectives as per the previous step. The permutation of embedding of metacognitive training within learning content (i.e., embedded or detached) and domain-generality (i.e., domain-specific or domain-general) leads to four possible configurations (cf. classification matrix by Osman & Hannafin, 1992).

For domain-specific metacognitive training, it is recommended that metacognitive content is embedded within subject matter content (*domain-specific and embedded configuration*). Here, embedding enables learners to make the connection between metacognition and ongoing learning without much effort. This configuration is the most common approach to facilitate learning by supporting metacognition. To the extent that the metacognitive outcomes are applicable beyond the specific domain, this configuration can be used to improve domain-general metacognition (*domain-general and embedded configuration*). However, without additional support or emphasis, learners will likely struggle to identify and isolate what aspects can be used in different learning situations and what aspects are specific to the subject matter (Derry & Murphy, 1986; Osman & Hannafin, 1992).

For domain-specific metacognitive training, it is possible that metacognitive content is detached from subject matter content (*domain-specific and detached configuration*). This emphasizes the role of metacognition as different from subject matter learning, but makes it more difficult for learners to make the connection. We do not recommend this approach, as previous research shows that domain-specific metacognitive training is more effective when embedded in domain-specific content (Bannert & Mengelkamp, 2013; Veenman et al., 2006). When the objective is to transfer metacognition to similar or different future learning situations, domain-general metacognitive training that is detached from subject matter content is recommended (*domain-general and detached configuration*). This is the configuration we predominantly investigated in this dissertation and that allows metacognitive training tools to be combined with existent subject matter learning across a wide range of domains and contexts.

Second, we consider the way in which metacognitive training content is combined with gameplay. We identified three possible types of integration: exogenous (metacognitive training is not part of the GBLE), extrinsic (metacognitive training is part of the GBLE but not integrated with the gameplay) and intrinsic (metacognitive training is integrated with the gameplay within the GBLE).

Here, exogenous integration is beyond our scope of designing *game-based* metacognitive training. We refer to work by Ke (2008a, 2008c) for examples of combining GBL with exogenous metacognitive interventions and to work by Lin (2001), Veenman et al. (2006), and Bannert and Mengelkamp (2013) for more generic approaches to metacognitive training.

Previous work on GBL recommends intrinsic integration of learning content with gameplay, such that engaging with the game coincides with engaging with the learning content. However, through our work, we have become increasingly convinced that such a type of intrinsic integration is not optimal when the learning content is metacognitive training. Predominantly, intrinsic integration seems to make it hard for learners to distinguish between what is relevant only within the game (e.g., its setting, narrative, environment) and what is relevant for real-world learning (e.g., learning goals, learning strategies, educational context). Extrinsic integration of metacognitive training content with gameplay, such as when alternating between gameplay activities and metacognitive activities or when presenting metacognitive activities before and after domain-specific training, seems better able to foster metacognition in learners.

Step 3: configuring the remaining dimensions of the framework

The remaining dimensions of the design framework describe aspects of metacognitive instruction (i.e., explicit/implicit, system-controlled/learner-controlled) and gameplay (i.e., social/individual, competition/collaboration, deliberate/reactive, fidelitous/fictitious). Here, again, the design principles provide a basis to make informed design decisions.

In terms of explicit or implicit instruction, we recommend offering explicit instructions and support at first. We have found that learners, experienced or less experienced, quickly get lost in navigating metacognitive support in addition to their ongoing learning process. To avoid overwhelming learners with instruction and support when not needed, we propose that such metacognitive training be faded over time (adaptive) or be allowed to turn on and off (personalized/configured). This relates this dimension to that of system-controlled or learner-controlled metacognitive training. At first, learners seem to need some amount of system-control to avoid extraneous cognitive load, however, eventually, learners seem to desire an increased amount of autonomy and control to avoid disengagement. This is in line with our findings that learners persistently recommend metacognitive training for other learners who are less experienced than themselves, regardless of the current level of support.

To allow individuals to develop metacognition at their own tempo, and to allow them the safety to explore their own ideas and approaches, we recommend allowing individual use of the GBLE. At the same time, we recommend supporting meaningful social interactions that promote social identification and reinforcement of effective learning behaviors. In other words, the design should combine individual instruction and support of metacognition with social interactions related to learning

(Järvelä, Malmberg, Sobocinski, & Kirschner, 2021; Panadero & Järvelä, 2015; Usart et al., 2011). Such interactions must be actively encouraged, or learners will not make use of such features, for example through GBL-elements of competition and collaboration. Care must be taken to avoid competition on variables involving learning performance, as this can induce anxiety in learners (cf. Brady, Seli, & Rosenthal, 2013), however, competition on effort is less confronting. Collaboration can be promoted in the exchange of ways of learning and metacognitive content such as strategies.

When metacognition is to be intrinsically integrated with gameplay, we recommend adopting a deliberate and step-by-step type of gameplay. This ensures that learners have sufficient time to consider and select their actions. We further recommend that gameplay is as fidelitous to the target learning situation as possible, to make sure that learners can make the connection between in-game experience and real-world learning. When metacognition is to be extrinsic to the gameplay, there is more room for reactive gameplay and to explore more fictitious settings and mechanics.

3.2 Towards a Theoretical Model of Game-Based Metacognitive Training

In this dissertation we focused on identifying and formulating intermediate-level design knowledge that is more general than specific instantiations, but not as general as a theory. We did however gain theoretical insights. Through this work, we have developed a more refined perspective on metacognition, GBL, and the combination thereof. In this section we discuss our reconsideration of metacognition and GBL and integrate our perspective with previous work from different disciplines. We put forward a possible theoretical model that could help to improve understanding of the design of game-based metacognitive training, with the aim of inspiring future work from other researchers.

Reconsidering Metacognition

As there is ongoing debate on what is and what is not metacognition, we put significant effort into describing, defining, and altogether demarcating what our conceptualization of metacognition for the purpose of this dissertation is. We adopt a perspective positioning metacognition within self-regulated learning and focused on the somewhat operational view of how metacognition improves learning in terms of effectiveness (i.e., increased learning performance) and efficiency (i.e., reduced resource use).

While recognizing that self-regulated learning further encompasses social and affective aspects of learning, it is not the primary focus of our research to investigate these aspects. However, we did find that learners have expectations and experiences that are relevant for the metacognitive perspective of learning. For example, we found more than a few students who experienced metacognitive training as a means of reducing stress and anxiety. The increased self-efficacy resulting from a better understanding of learning and a better control of how learning proceeds impacted students both cognitively and affectively.

In our work we used the original MAI-questionnaire (Schraw & Dennison, 1994), as well as a shorter and revised version (Harrison & Vallin, 2018). While there are strong links between these scales and metacognitive knowledge and skills, many scholars advise against the use of such self-report measures (cf. Harrison & Vallin, 2018; Schellings & Van Hout-Wolters, 2011). More thorough consideration, selection, and administering of such measures could have provided a stronger basis for assessing such impacts.

The links between metacognition and social aspects of learning are also clear from the desire of students to collaborate on improving learning. Benefiting from such shared regulation among peers is an interesting area for future research. In particular both the affective perspective and the social perspective relate well to the affordances of GBLEs, as is apparent from the gameplay design dimensions in our framework. Further research could help identify the relevant design principles and mechanisms to facilitate this (Betts & Rothschild, 2020; Novak, 2017)

In this dissertation we focused on metacognition as an important aspect of learning, working towards the achievement of learning objectives. Zooming out and looking at the bigger picture, we now consider metacognition as an important aspect of a learner: it determines the perspective on oneself as a learner and fosters self-regulated learning in a dynamic and reciprocal way. For example, the MAPS-model relates self-regulated learning to four components working together (Frazier, Schwartz, & Metcalfe, 2021): (i) a notion of *possible future selves* that embodies goals and motivates behavior; (ii) effective *metacognition* as a means of implementing change; (iii) *agency* to act towards increased competence, self-efficacy, and engagement; resulting in (iv) *behavioral outcomes* of achieving goals or sub-goals. Such a broader view enables us to view metacognition as a means to increase learners' success and wellbeing, not to mention its benefit as a foundation for life-long learning. Further research along these lines could help inform the design of game-based metacognitive training aimed at improving future learning in a more wholesome fashion.

Reconsidering Game-Based Learning

Throughout this dissertation, we have adopted a broad interpretation of what constitutes a GBLE. We used the term to cover a wide range of digital tools that range from games, game-like simulations, to gamified solutions. This definition shifts slightly throughout the work as well: in the literature review the term is used more loosely than in later chapters. The definition provided in the first chapter is system-based (i.e., a system in which players engage in an artificial conflict), but with the presumption that interaction, motivation, and learning emerge from such systems when well-designed for their purposes. This function of GBLEs extends across the range of tools we meant to discuss and serves as a point of reference.

Focusing on its purpose of contributing to learning and to motivation, we have bypassed a discussion of what exactly constitutes a game, a serious or educational game, a game-based learning environment, or – at the other end of such a spectrum – gamification (see Deterding et al. (2011) for a useful way of distinguishing between such approaches; see Slussareff et al. (2016) for a broader discussion of games for learning). This is apparent when, for example, comparing from Chapter 6 the design used in Design Experiment #1 and Design Experiment #4. Whereas the former can be considered a game in its narrow sense, the latter can be considered a gamified digital tool but is debatably a game.

We find it more insightful to consider what role the different elements play within the design of a digital GBLE. To what extent are elements incorporated in the design to facilitate learning (e.g., a question prompt is presented to let a learner explain a particular outcome in the game) and to what extent are elements incorporated to facilitate motivation and engagement (e.g., a question prompt is presented in a comical way by one of the in-game characters)? Or, perhaps more interestingly, when can elements successfully embody both roles (e.g., feedback on the learning objectives coincides with feedback on gameplay objectives)? In this interpretation, we focused predominantly on individual interactions of learners with such a system, while only limitedly looking at opportunities to leverage the social possibilities of games.

As demonstrated in the previously outlined design process, we conceptualize the design of GBL as considering design choices in terms of the relationships between the desired outcomes on the one hand and selected elements and mechanisms on the other hand. However, the devil is often in the details of the design. It is clear that the complexity in the design of GBLEs cannot be fully unpacked into its individual components. In other words, the experience of GBL emerges not from the sum of its constituents but rather from their intricate coherence and interrelationships. However, we do think that designers and researchers can be more specific still about what they make, why they make it, and how they hypothesize it to achieve the proposed effects. The design framework and design principles we put forward in this dissertation provide a starting point to improve such specificity and facilitate and demonstrate a transformation of design goals into specifications of the design artifact (Ke et al., 2019).

Combining Metacognition with GBL

Our experiments provide evidence pointing in the direction of complications in providing metacognitive training through GBL. However, the few instances of GBLEs that form our samplings of the dimensions of the DFM-GBL cannot begin to cover the design space. Two areas for further research stand out in particular. First, in our work we focus on domain-general metacognitive training that is agnostic to the content or domain of learning. As discussed, this complicates the transfer of training to task as well as the design of gameplay. Further research should concentrate on design configurations that blend domain-general and domain-specific elements to balance the benefits and drawbacks of both approaches. Second, in our work we focus mostly on individual play. While the final design experiment includes social mechanisms and identifies corresponding design principles, there is ample room for further work. When regarding GBLEs more as starting points for interaction, exchange, and growth in a playful way, metacognition and self-regulated learning may be promoted from a social constructivist perspective.

At the start of this dissertation we conceptualized metacognition using a distinction between the cognitive level of a learner conducting learning activities and a metacognitive level of monitoring and regulating cognition. Consider now how Martinez-Garza and Clark (2017) conceptualize GBL from a more general two-system theory of human cognition. They propose a distinction between two cognitive stances of users of GBLEs: a *playing stance* and a *learning stance*. In the playing stance, users are seeking to optimize in-game performance and continue play. As such, they build within their mind an interactive model that represents the practical knowledge of how to act successfully within the game. In the learning stance, users are seeking to make sense of how the game operates. As such, they build a mental model of the entities, relationships between entities, and causal structure of the game. The better gameplay is designed to intrinsically embed and align with the learning content, the better the mental model that is developed represents the relevant outcomes of GBL.

As it is, this model goes a long way towards offering a cognitive explanation for why intrinsic integration is desirable (cf. Arnab et al., 2015; Habgood & Ainsworth, 2011), for how narrative can serve as a cognitive framework aiding learning (cf. Barab, Dodge, Tuzun, Job-sluder, et al., 2007; Dickey, 2006), as well as for why it is often hard to achieve more complex higher-level learning outcomes with current approaches to the design of GBL (cf. Graesser, 2017; Ke, 2016). Moreover, by extension, we think such a model could further extend insights on game-based metacognitive training and the challenges identified throughout this dissertation.

Table 7.1: Extension of the 2SM model with a metacognitive stance.

	Model	Processes	Goals
playing stance	interactive model of how the game works operationally	application of execution rules, evaluation of rule effectiveness after the fact	achieve desired psychological states, maintain agency
learning stance	mental model of the subject matter embedded in the gameplay	definition and refinement of strategic rules, testing their effectiveness	signal understanding of the interactive model, bolster agency, and self-efficacy
metacognitive stance	second-order mental model of learning	monitoring and regulating learning	warrant effective and efficient learning from gameplay

If we consider the learning stance as parallel to the cognitive view of conducting learning activities, we can imagine a third stance that parallels the metacognitive view of monitoring and regulating learning activities. As shown in Table 7.1, a metacognitive stance is concerned with building a second-order mental model of learning and facilitates monitoring and regulation of learning. In other words, in terms of our conceptual model of metacognition that differentiates the learning process (object-level) from metacognition (meta-level), we consider the learning stance and associated mental model as the object-level of the learning process, and we consider the metacognitive stance and associated mental model as the meta-level.

Such an extension could potentially explain the difficulties we encountered when designing gameplay to facilitate detached and domain-general metacognitive training. In this case, we are trying to design gameplay to facilitate a player stance and to facilitate a metacognitive stance, while the learning stance cannot be facilitated: as ongoing learning takes place outside of the GBLE, essentially an important and interconnecting layer between the two stances is absent. As we have already noticed that the far transfer required from detached and domain-general training is demanding, this extended model could further detail the different steps of transfer from GBL.

Furthermore, such an extension could also potentially explain why it is hard to integrate metacognitive training with gameplay. As a player is playing the game, through the playing stance the interactive model is applied and improved in a somewhat automatic way. At certain moments, for example when indirect feedback is provided by the game, a player switches to the learning stance and more consciously considers strategic improvements to become more successful in the game – ideally through an increased understanding of the subject matter. However, to then take yet another step back and adopt a metacognitive stance breaks the links with the gameplay: we are asking the user to inspect learning, but not playing, hence asking an effort to redefine the scope of inquiry. It appears that, for many players, the cognitive demands of such a view exceed what resources are available during interaction with a GBLE.

Naturally, further research would be necessary to explore whether these considerations of a metacognitive stance in GBL have merit. It would be interesting to consider a GBLE in which the three different stances are incorporated in distinct ways – for example in terms of self-explanation prompts, in terms of the feedback the game provides, and in terms of the measured outcomes of working with the GBLE over time. Building from our work, we foresee that investigating the design of game-based metacognitive training from this prescriptive could improve design knowledge of how different elements work together towards different models and stances within the player.

4. On Educational Design Research

In this dissertation we conducted educational research by designing, evaluating, and learning from our designs when implanted in artefacts and used within in real-world educational contexts. We adopted design research as a methodology that would (1) provide synergy between knowledge contributions and practical contributions, (2) accommodate an interdisciplinary integration of concepts and methods, (3) provide ways of generalizing findings beyond a specific instantiation, (4) support the study of solutions and half-solutions in real-world practice settings, and (5) support the iterative design and improvement of such solutions. Specifically, we used research-through-design as a way of uncovering design knowledge through systematic research. With the aim of informing future researchers in education using educational research through design as a way of learning about education, we present our insights on this learning process and its outcomes.

4.1 Learning from Designed Artefacts

Through the literature review, we found that many descriptions of different games and metacognitive mechanisms within them lack sufficient specificity to allow comparisons and transfer in any straightforward way. Sometimes it is also difficult to understand what the GBLE itself is like and, therefore, extremely difficult to understand and relate the evaluation results to factors in the design. When studying designed artefacts, not only the phenomena under study are of concern; the causal factors in the design are at least as relevant. This emphasizes the need to annotate the design through its iterations and to identify and specify the key elements and mechanisms by which it operates or is hypothesized to operate (cf. Braad, Folkerts, & Jonker, 2013). It is not only important to understand if something works as intended, but perhaps it is more important to know and understand why and how it works or does not work.

We elaborated intermediate-level design knowledge within the interdisciplinary context of games and learning. As we seek to generalize insights from a particular instantiation to be applied to different new instantiations, we need ways of identifying how they are similar and how they are different. Initially, design-science research proponents such as March and Smith (1995) were optimistic that the study of instantiations would provide information about the underlying models, methods and constructs. However, Van den Akker et al. (1999) stipulate that instantiations only sample one case within one context. Correspondingly, information about the context and the instantiation must be critically scrutinized and, at a minimum, addressed when discussing experiments and their findings (cf. Holleman, Hooge, Kemner, & Hessels, 2020).

At least as much notice must be taken of how the instantiation represents the underlying theory (in the large), the hypotheses under scrutiny (in the small), or something in between them in the derivation chain (cf. Scheel, Tiokhin, Isager, & Lakens, 2021). If an artefact is used to test an assumption, then it is critical that the artefact embodies this assumption. Unfortunately, it is virtually unavoidable that the artefact will embody other known and unknown assumptions. This is the same conundrum as the extent to which the context in which a hypothesis is tested can be related to the context to which the conclusions are generalized, only this time around for instantiations instead of contexts (Dunlosky, Bottiroli, & Hartwig, 2009). Researching designs through testing their instantiations in the real world brings with it the complexity of specifying how this artefact relates to that world.

One way of dealing with the complexity of how an instantiation represents the proposed theory or hypothesis is to make explicit which assumptions are made, based on which theory, and how these assumptions are effectuated in the instantiation. For example, conjecture mapping is a technique proposed to make such conjectures and their embodiment in the artefact explicit (Sandoval, 2014; Sandoval & Bell, 2004). Both conjectures about how the design should function and conjectures about how that function could produce the intended outcomes are included. In this work, we strive for a similar clarity about the design, its constituent elements, its working mechanisms, and the way in which we hypothesize it to produce its outcomes. We hope that these ideas inspire others to further help characterize designs in a way that promotes advancing insights into its underlying design knowledge.

4.2 Learning in the Real World

In all of the designs and studies we involved individual students or groups of students as co-creators. Such collaborations have helped us to atone our communication and instructions within the tools and within the training sessions to the intended audience. Most prominently however, such collaborations have offered us the crucial insights into how students learn and how they would make use of tools for learning. We recommend using such pre-evaluation insights to adjust designs accordingly for the settings they are intended to be used in.

We opted to evaluate our designs in field experiments: in real classrooms, with real teachers and real students, engaging in real-world learning. With this choice, we introduced real-world 'noise' into our work: we evaluated our GBLEs with different students, working with different teachers, across different courses and programs taught in different languages (cf. Brown, 1992). At the same time, we encountered real-world phenomena that are relevant to our design and to our research. Thus, if our interventions turn out to be robust under real-world conditions, this bodes well for the external generalizability of our findings.

In comparison to random-controlled trials our studies are less replicable and less decisive in terms of confirming or contradicting hypotheses. However, for our purpose of better understanding crucial design choices and how they affect learners, they provide more relevant insights. For example, we learned how students perceive educational tools and how they make deliberate choices about which tools to use, for what purpose, and with what intensity. We advocate such rich studies, that capture a wide range of quantitative and qualitative insights. Through our design framework, we can compare and analyze findings across a number of similar factors in the design, underlining how an artefact does not stand alone but represents one of many possible samplings of the design space. As such, the dimensions of our design framework are not unlike a research programme in the sense of Binder and Redström (Binder & Redström, 2006; Redström, 2011).

In essence, the selection of a particular type of study concerns a classical tradeoff between experimental control (minimizing the unaccounted effects of confounding variables) and representative design (maximizing how the experimental conditions represent those over which generalization is to be achieved; cf. Hammond (1998) and Kihlstrom (2021)). Even though generalizability of the findings remains an issue, it also remains as a question to what extent lab-findings would generalize to real world settings (cf. Holleman et al., 2020). When the phenomena under study are of a complexity that is hard to reproduce in controlled settings, it is more insightful to study them in the real-world and accept the corresponding limitations on generalization. In studying our interventions within the complexity stemming from the interaction between person, environment, and task, what we earlier referred to as noise is not noise. While unpredictable and hard to measure, these factors are part of a real-world educational setting. If we seek to understand well any interventions within this setting, such "noise" needs to be part of educational research.

Throughout this dissertation, we have presented our work and our designs as a linear exercise, where each subsequent design has benefited from the findings and insights derived from the previous designs. Thus, we went from identifying current insights and practices in how GBL addresses metacognition, to proposing a model of relevant design areas to consider, and then proceeding to experiment with designing digital metacognitive tools with various numbers of game elements included. Ideally, one would like to alternate working prospectively (i.e., based on previous work, speculate informedly about the design and outcomes of an artefact under design) with working retrospectively (i.e., based on evaluation findings, speculate informedly about adjustments to that design and its implications for future designs). Unfortunately, neither a design process nor a research process often unfolds in such a linear way.

The iterative design of artefacts, beyond intentionally being steered in a certain direction, will also unintentionally 'drift' in various directions (Krogh & Koskinen, 2020). Redström (2011) describes ways in which drift is caused by mostly practical matters, and how a research programme can counter such drift. For serious game design in specific, work by Khaled et al. (2018)provides relevant directions and practical suggestions for tracing design space trajectories in this way. The research in this dissertation certainly experienced drift. The timing of real-world education within an institution had a strong imperative role, as it determined to a large extent when and where an artefact – ready or not – must be evaluated. Another source of drift was the availability of time and students to help work on conceptualizing and developing artefacts and, as such, determining the maturity of an artefact. If future work on design research could offer ways of controlling, or at least monitoring, the occurrence and direction of such drift in a systematic way and such that it does not occur unconsciously, that would be a great improvement.

4.3 Types of Design Knowledge

If research through design is learning, then design knowledge is its learning outcome. Within the area of designing GBLEs to foster metacognition, we contributed by organizing design knowledge in a design framework, expanding design knowledge with design principles and recommendations, and demonstrating design knowledge through artefacts and evaluations. As such, we focused on design knowledge that is prescriptive in the sense that it aids other designers and researchers by prescribing, with varying degrees of confidence, what to do or not do within a design to achieve a particular effect (Chandra, Seidel, & Gregor, 2015).

As noted, we also focused on design knowledge that resides between concrete artefacts and abstract theories or, in other words, intermediate-level design knowledge (Höök & Löwgren, 2012). As such, we strived to produce design knowledge that is relevant beyond a specific instance intended for a specific context and, consequentially, we attempted to make inferences from such particular instantiations. For example, our recommendations are based on a few artefacts and design experiments, but represent, with some confidence, relevant design knowledge for similar future designs. What we struggled with, however, is the extent to which a design principle could be regarded when isolated from its immediate context of use. In addition to its generalizability, its semantic gravity, or the degree to which the meaning of a concept relates to its context (Dong, Maton, & Carvalho, 2014), played a role in determining how widely or narrowly a design principle applied. There is room for further theoretical concepts and vocabulary to better communicate about the intricacies of formulating intermediate-level design knowledge.

Making a case for a particular type of intermediate-level design knowledge (i.e., strong concepts), Höök and Löwgren (2012) introduced more generally applicable terms of *horizontal and vertical grounding* as ways of transforming design knowledge to academic contributions. The process of horizontal grounding concerns relating a particular concept to similar concepts and focusing on their similarities and differences. Here, horizontal refers to the concepts that "sit next" to the concept under study. Our design framework, with design dimensions intended to ease navigation of the design space, facilitates such horizontal grounding by suggesting in which ways GBLEs are similar or different. The process of vertical grounding concerns relating a concept to similar concepts that are either more abstracted (i.e., "sit closer" to a theory) or more instanced (i.e., "sit closer" to an instantiation). This process has particularly helped us overcome interdisciplinary boundaries; for example, when seeking to identify design principles from specific and instanced examples, or when considering the applicability of generic design principles of metacognitive training to specifically GBL. In other words, we found these processes useful at the more general level of developing and articulating design knowledge rather than to describe and position artefacts alone.

Where Höök and Löwgren (2012) describe design knowledge in somewhat tacit terms of what is similar and different to it, and what more abstract and more concrete design knowledge it relates to, Plomp (2013) provides a much more explicit form that includes specifying its context and characteristics in near-mathematical form (i.e., in context Z (with certain characteristics) the intervention X (with certain characteristics leads to outcomes Y1, Y2, …, Yn). Thus, design knowledge not only varies by its contents, but also by its underlying structure (Dong et al., 2014) and the degree to which it is tacit or explicit. For example, design knowledge could be positioned along a set of hierarchical levels, from high-level design knowledge to context-specific design knowledge (Kolarić, Beck, & Stolterman, 2020). These different forms are not better or worse ways of specifying design knowledge; rather they have different affordances and facilitate different forms of usage (Maton, 2009). In our work, we explored two of such usages. We strive for our design knowledge to be re-usable in slightly different instantiations and across slightly different contexts, and we strive for our design knowledge to advance understanding of the design of game-based metacognitive training. There is, however, room for a better characterization of what types of design knowledge and what types of formulation are helpful towards such different usages.

5. To Conclude

Unfortunately, the work in this dissertation and the insights and interventions we developed came too late to be of help to Alex. Perhaps Alex never developed the level of metacognition that we, as teachers, expected and hoped to see at graduation. Instead, Alex has received extensive and one-on-one guidance from a highly experienced teacher. Step-by-step and with considerable effort, he has been able to meet the criteria of the study program and has received the corresponding diploma. This is a nice outcome for Alex, who could now move on with his life, however, at the same time this is unsatisfactory. Apparently, a study program in higher education can be completed without demonstrating self-regulatory skills or metacognition.

This is particularly unsatisfactory when we regard this past case in the light of the future of higher education. To emphasize that now not only the researcher or designer but mostly the teacher in me speaks out, I will switch to first person singular.

First, issues that occur for students during learning and studying are currently addressed using a signaling (e.g., mentor meetings) and remedial (e.g., extra support) approach. Instead of taking action when there appears to be a problem, I would like to advocate enabling students to detect issues and helping them to indicate and address these. Through the development of self-regulation and metacognition, students increase their understanding of their own learning. With increased understanding comes an increased sense of control of learning, improving effectiveness, efficiency, and, ultimately, enjoyability of learning.

Second, the end qualifications of study programs are currently predominantly formulated in terms of the knowledge, skills, and attitudes that are linked to corresponding professions or careers. When these end qualifications have been sufficiently demonstrated, a diploma is awarded. However, this emphasis on knowledge and skills in relation to current professions is under increasing pressure. For the future, it is less clear which professions and careers will exist and, as a result, which combinations of knowledge and skills will be needed.

Third, within a life and a career, higher education is currently heavily front-loaded: the emphasis is on spending three to five adolescent years preparing someone for approximately 50 years of professional work. The contents of such training are, within this life-long perspective, aimed at relatively short-term knowledge and skills that may quickly prove to be less relevant.

This does not mean that knowledge or skills do not have value: I am strongly convinced that learning begins with understanding the relevant concepts, their interrelationships, and being able to let understanding guide behavior. However, other and complementary competencies are important as well. Creativity. Critical thinking. Self-regulation. Metacognition. Learning ability. And, overall, problem-solving skills. Clearly, there is now not enough structural attention for developing these skills. Some questions that the higher education institutions, their study programs and their teachers should seek to answer are, in this respect:

- Shouldn't the development of metacognition and self-regulation among students form a necessary part of any study in higher education?
- Shouldn't learning ability be part of the end qualifications of any study and, consequentially, of the awarded diploma?
- Shouldn't teachers be facilitated in developing the knowledge, skills, and tools to help their students grow in this broader sense?
- Shouldn't educational research surrounding such interventions at all times be a structural and integral part of educational innovation?

To conclude this dissertation, let us look ahead and consider the possible and desired outcomes of this work in the foreseeable future.

The many students and the many teachers that I have spoken with about learning, studying, self-regulation, metacognition, and generally my research, have always responded with a positive interest in what they could take from this perspective: in terms of specific approaches in learning and teaching, in terms of tools to use and provide, and in terms of insights to take into account in their day-to-day educational activities. Insofar as this is an indicator of a fertile ground for a more widespread and more coordinated approach to training metacognition within higher education, the impression is good. There is room for – and more importantly benefits to be had from – a domain-general training approach that links in subtle ways to domain-specific contexts of particular studies and subject matters.

It is my hope that current and future students can benefit from an increased attention to the role of metacognition in learning, and from specifically designed interventions – digital and analogue, game-based and otherwise – that can aid them in the way that they need. To the extent that the ideas, design knowledge, prototypes and general thoughts in this dissertation have contributed to bringing that future somewhat closer, I consider it a success.

References

Abt, C. C. (1970). *Serious Games*. New York: Viking Press.

Aldemir, T., Celik, B., & Kaplan, G. (2018). A qualitative investigation of student perceptions of game elements in a gamified course. *Computers in Human Behavior*, *78*, 235–254.

Altıok, S., Başer, Z., & Yükseltürk, E. (2019). Metacognitive awareness of undergraduates through using an e-educational video environment. *Computers & Education*, *139*, 129–145.

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivation processes. *Journal of Educational Psychology*, *80*(3), 260–267.

Amory, A. (2007). Game object model version II: A theoretical framework for educational game development. *Educational Technology Research and Development*, *55*(1), 51–77.

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. *Theory Into Practice*. Addison Wesley.

Andriessen, D., & Van Turnhout, K. (2023). Stromingen in ontwerpgericht onderzoek. In K. Van Turnhout, D. Andriessen, & P. Cremers (Eds.), *Handboek ontwerpgericht wetenschappelijk onderzoek* (pp. 77–98). Amsterdam: Boom Uitgevers.

Arnab, S., De Freitas, S., Bellotti, F., Lim, T., Louchart, S., Suttie, N., … De Gloria, A. (2012). Pedagogy-driven design of serious games: An overall view on learning and game mechanics mapping, and cognition-based models. Serious Games Institute.

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., De Freitas, S., Louchart, S., … De Gloria, A. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology*, *46*, 391–411.

Arroyo, I., Woolf, B. P., Burelson, W., Muldner, K., Rai, D., & Tai, M. (2014). A multimedia adaptive tutoring system for mathematics that addresses cognition, metacognition and affect. *International Journal of Artificial Intelligence in Education*, *24*(4), 387–426.

Asgari, M., & Kaufman, D. (2004). Relationships among computer games, fantasy, and learning. *Proceedings of the 2nd International Conference on Imagination and Education*, 1–8.

Azevedo, R. (2005a). Computer environments as metacognitive tools for enhancing learning. *Educational Psychologist*, *40*(4), 193–197.

Azevedo, R. (2005b). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist*, *40*(4), 199–209.

Azevedo, R. (2020). Reflections on the field of metacognition: issues, challenges, and opportunities. *Metacognition and Learning*, *15*, 91–98.

Azevedo, R., Behnagh, R. F., Duffy, M., Harley, J. M., & Trevors, G. (2012). Metacognition and self-regulated learning in student-centered learning environments. In *Theoretical Foundations of Learning Environments* (pp. 171–197). Routledge.

Azevedo, R., Cromley, J. G., Winters, F. I., Moos, D. C., & Greene, J. A. (2006). Using computers as metacognitive tools to foster students' self-regulated learning. *Technology, Instruction, Cognition & Learning*, *3*, 97–104.

Azevedo, R., & Hadwin, A. F. (2005). Scaffolding self-regulated learning and metacognition - Implications for the design of computer-based scaffolds. *Instructional Science*, *33*(5–6), 367–379.

Azevedo, R., & Jacobson, M. J. (2008). Advances in scaffolding learning with hypertext and hypermedia: a summary and critical analysis. *Educational Technology Research and Development*, *59*(93), 93–100.

Baker, L., & Brown, A. L. (1984). Metacognitive skills and reading. *Handbook of Reading Research*, *1*, 353–394.

Bandura, A. (1977). *Social Learning Theory*. Englewood Cliffs, New Jersey: Prentice-Hall.

Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, New Jersey: Prentice-Hall.

Bang, A. L., & Eriksen, M. A. (2014). Experiments all the way in programmatic design research. *Artifact*, *III*(2), 4.1-4.14.

Bannert, M., Hildebrand, M., & Mengelkamp, C. (2009). Effects of a metacognitive support device in learning environments. *Computers in Human Behavior*, *25*(4), 829–835.

Bannert, M., & Mengelkamp, C. (2013). Scaffolding hypermedia learning through metacognitive prompts. In R. Azevedo & V. Aleven (Eds.), *International Handbook of Metacognition and Learning Technologies* (pp. 171–186). Springer.

Bannert, M., & Reimann, P. (2012). Supporting self-regulated hypermedia learning through prompts. *Instructional Science*, *40*, 193–211.

Barab, S. A., Dodge, T., Tuzun, H., Job-sluder, K., Jackson, C., Arici, A., … Heiselt, C. (2007). The Quest Atlantis Project: A socially-responsive play space for learning. In B. E. Shelton & D. Wiley (Eds.), *The Educational Design and Use of Simulation Computer Games* (pp. 159–186). Rotterdam, The Netherlands: Sense Publishers.

Barab, S. A., Dodge, T., Tuzun, H., Job-Sluder, K., Jackson, C., Arici, A., … Heiselt, C. (2007). The Quest Atlantis Project: A socially-responsive play space for learning. In B. E. Shelton & D. Wiley (Eds.), *The Educational Design and Use of Simulation Computer Games* (pp. 159–186). Rotterdam, The Netherlands: Sense Publishers.

Barab, S. A., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development*, *53*(1), 86–107.

Bedwell, W. L., Pavlas, D., Heyne, K., Lazzara, E. H., & Salas, E. (2012). Toward a taxonomy linking game attributes to learning. *Simulation & Gaming*, *43*(6), 729–760.

Bessarabova, E., Piercy, C. W., King, S., Vincent, C., Dunbar, N. E., Burgoon, J. K., … Lee, Y. H. (2016). Mitigating bias blind spot via a serious video game. *Computers in Human Behavior*, *62*, 452–466.

Betts, A. L., & Rothschild, M. K. (2020). Massively multiplayer online games as spaces for metacognition and self-regulated learning. In M. Farber (Ed.), *Global Perspectives on Gameful and Playful Teaching and Learning* (pp. 78–104). Colorado, CO, USA: IGI Global.

Binder, T. (2019). Commentary: "Experiments all the way in programmatic design research" revisited. *Journal of Design Practice*, *6*, 1–2.

Binder, T., & Redström, J. (2006). Examplary design research. In K. Friedman, T. Love, E. Côrte-Real, & C. Rust (Eds.), *Wonderground - DRS International Conference*.

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology*, *64*(1), 417–444.

Boekaerts, M. (1997). Self-regulated learning: A new concept embraced by researchers, policy makers, educators, teachers, and students. *Learning and Instruction*, *7*(2), 161–186.

Boekaerts, M., & Cascallar, E. (2006). How far have we moved toward the integration of theory and practice in self-regulation? *Educational Psychology Review*, *18*, 199–210.

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., … Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, *94*, 178–192.

Braad, E., Degens, N., Barendregt, W., & IJsselsteijn, W. A. (2021). Development of a design framework for metacognition in game-based learning. *Journal of Interactive Learning Research*, *32*(4), 295–323.

Braad, E., Degens, N., Barendregt, W., & IJsselsteijn, W. A. (2022). Improving metacognition through self-explication in a digital self-regulated learning tool. *Educational Technology Research and Development*.

Braad, E., Degens, N., & IJsselsteijn, W. A. (2019a). MeCo: A digital card game to enhance metacognitive awareness. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th European Conference on Games Based Learning* (pp. 92–100). Sonning Common, United Kingdom: Academic Conferences and Publishing International.

Braad, E., Degens, N., & IJsselsteijn, W. A. (2019b). Towards a framework for metacognition in game-based learning. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th European Conference on Games Based Learning* (pp. 101–109). Sonning Common, United Kingdom: Academic Conferences and Publishing International.

Braad, E., Degens, N., & IJsselsteijn, W. A. (2020). Designing for metacognition in game-based learning: A qualitative review. *Translational Issues in Psychological Science*, *6*(1), 53–69.

Braad, E., Folkerts, J., & Jonker, N. (2013). Attributing design decisions in the evaluation of game-based health interventions. In B. Schouten, S. Fedtke, T. Bekker, M. Schijven, & A. Gekker (Eds.), *Proceedings of the 3rd European Conference on Gaming and Playful Interaction in Health Care* (pp. 61–74). Springer.

Braad, E., Žavcer, G., & Sandovar, A. (2016). Processes and models for serious game design and development. In R. Dorner, S. Gobel, M. D. Kickmeier-Rust, M. Masuch, & K. Zweig (Eds.), *Entertainment Computing and Serious Games*. Springer.

Brady, M., Seli, H., & Rosenthal, J. (2013). Metacognition and the influence of polling systems: How do clickers compare with low technology systems. *Educational Technology Research and Development*, *61*(6), 885–902.

Braun, V., & Clarke, V. (2012). Thematic analysis. In H. Cooper (Ed.), *APA Handbook of Research Methods in Psychology* (pp. 57–71). American Psychological Association.

Broadbent, J., Panadero, E., Lodge, J. M., & De Barba, P. (2020). Technologies to enhance self-regulated learning in online and computer-mediated learning environments. In M. J. Bishop, E. Boling, J. Elen, & V. Svihla (Eds.), *Handbook of Research in Educational Communications and Technology* (pp. 37–52). Springer.

Brown, A. L. (1978). Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in Instructional Psychology (Volume 1)* (pp. 77–165). New Jersey, USA: Lawrence Erlbaum Associates.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences*, *2*(2), 141–178.

Brown, A. L., Bransford, J. D., Ferrara, R., & Campione, J. (1983). Learning, remembering, and understanding. In J. H. Flavell & E. M. Markman (Eds.), *Handbook of Child Psychology* (pp. 77–166). New York: Wiley.

Brown, A. L., & Palinscar, A. S. (1989). Guided, cooperative learning and individual knowledge acquisition. In Lauren B. Resnick (Ed.), *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser* (pp. 393–451). New York: Routledge.

Burguillo, J. C. (2010). Using game theory and competition-based learning to stimulate student motivation and performance. *Computers & Education*, *55*(2), 566–575.

Callender, A. A., Franco-Watkins, A. M., & Roberts, A. S. (2016). Improving metacognition in the classroom through instruction, training, and feedback. *Metacognition and Learning*, *11*(2), 215–235.

Carpenter, J., Sherman, M. T., Seth, A. K., & Fleming, S. M. (2019). Domain-general enhancements of metacognitive ability through adaptive training. *Journal of Experimental Psychology: General*, *148*(1), 51–64.

Carvalho, M. B., Bellotti, F., Berta, R., De Gloria, A., Sedano, C. I., Hauge, J. B., … Rauterberg, M. (2015). An activity theory-based model for serious games analysis and conceptual design. *Computers & Education*, *87*, 166–181.

Castronovo, F., Van Meter, P. N., & Messner, J. I. (2018). Leveraging metacognitive prompts in construction educational games for higher educational gains. *International Journal of Construction Management*, *22*(1), 19–30.

Chandra, L., Seidel, S., & Gregor, S. (2015). Prescriptive knowledge in IS research: Conceptualizing design principles in terms of materiality, action, and boundary conditions. In *48th Hawaii International Conference on System Sciences Prescriptive* (pp. 4039–4048). IEEE.

Charles, D., Hanna, C., Paul, R., & Charles, T. (2012). Rapid development of games inspired metacognitive learning experiences using Moodle and Gamemaker. In P. Felicia (Ed.), *Proceedings of the 6th European Conference on Games Based Learning* (pp. 93–101). Cork, Ireland: Academic Conferences.

Chen, C.-H., Shih, C.-C., & Law, V. (2020). The effects of competition in digital game-based learning (DGBL): A meta-analysis. *Educational Technology Research and Development*, *68*, 1855–1873.

Chen, Z.-H., & Lee, S.-Y. (2018). Application-driven educational game to assist young children in learning English vocabulary. *Educational Technology & Society*, *21*(1), 70–81.

Clarebout, G., Elen, J., Juarez Collazo, N. A., Lust, G., & Jiang, L. (2013). Metacognition and the use of tools. In R. Azevedo & V. Aleven (Eds.), *International Handbook of Metacognition and Learning Technologies* (pp. 187–195). Springer.

Clarke, V., & Braun, V. (2014). Thematic analysis. In A. C. Michalos (Ed.), *Encyclopaedia of Quality of Life and Well-Being Research* (pp. 6626–6628).

Cloude, E. B., Taub, M., Lester, J. C., & Azevedo, R. (2019). The role of achievement goal orientation on metacognitive process use in game-based learning. In S. Isotani, E. Millán, A. Ogan, P. Hastings, B. McLaren, & R. Luckin (Eds.), *Artificial Intelligence in Education* (pp. 36–40). Springer.

Cnossen, Y. (2009). *Fostering self-directed learning in a competency-based learning environment*. Open Universiteit Nederland, Heerlen, The Netherlands.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*, 661–686.

Connor, C. M., Day, S. L., Zargar, E., Wood, T. S., Taylor, K. S., Jones, M. R., & Hwang, J. K. (2019). Building word knowledge, learning strategies, and metacognition with the word-knowledge e-book. *Computers & Education*, *128*, 284–311.

Coulson, D., & Harvey, M. (2013). Scaffolding student reflection for experience-based learning: A framework. *Teaching in Higher Education*, *18*(4), 401–413.

Crocco, F., Offenholley, K., & Hernandez, C. (2016). A proof-of-concept study of game-based learning in higher education. *Simulation & Gaming*, *47*(4), 403–422.

Dansereau, D. F. (1978). The development of a learning strategies curriculum. In H. F. O’Neil (Ed.), *Learning Strategies* (pp. 63–82). New York: Academic Press.

Dansereau, D. F. (1985). Learning strategy research. In J. W. Segal, S. F. Chipman, & R. Glaser (Eds.), *Thinking and Learning Skills: Relating Instruction to Research* (pp. 209–241). Routledge.

De Villiers, M. R., & Harpur, P. A. (2013). Design-based research – the educational technology variant of design research: Illustrated by the design of an m-learning environment. In P. Machanick & M. Tsietsi (Eds.), *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference* (pp. 252–261). East London, South Africa: ACM.

Degens, N., Bril, I., & Braad, E. (2015). A three-dimensional model for educational game analysis & design. In *Proceedings of the Foundations of Digital Games Conference 2015*. Monterey Bay, California, USA.

Derry, S. J. (1989). Putting learning strategies to work. *Educational Leadership*, *47*(5), 4–10.

Derry, S. J., & Murphy, D. A. (1986). Designing systems that train learning ability: From theory to practice. *Review of Educational Research*, *56*(1), 1–39.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining gamification. In *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments* (pp. 9–11). ACM.

Dickey, M. D. (2006). Game design narrative for learning: Appropriating adventure game design narrative devices of interactive learning environment. *Educational Technology Research and Development*, *54*(3), 245–263.

Dickey, M. D. (2019). Narrative in game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 283–306). Cambridge, MA, USA: The MIT Press.

Dignath, C., & Büttner, G. (2008). Components of fostering self-regulated learning among students . A meta-analysis on intervention studies at primary and secondary school level. *Metacognition and Learning*, *3*, 231–264.

Dinsmore, D. L., Alexander, P. A., & Loughlin, S. M. (2008). Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review*, *20*, 391–409.

Dondlinger, M. J. (2007). Educational video game design: A review of the literature. *Journal of Applied Educational Technology*, *4*(1), 21–31.

Dong, A., Maton, K., & Carvalho, L. (2014). The structuring of design knowledge. In *The Routledge Companion to Design Knowledge* (pp. 38–49). Routledge.

Dunlosky, J., Bottiroli, S., & Hartwig, M. (2009). Sins committed in the name of ecological validity: A call for representative design in education science. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of Metacognition in Education* (pp. 430–441).

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques. *Psychological Science in the Public Interest*, *14*(1), 4–58.

Dweck, C. S. (1986). Motivational processes affecting learning. *American Psychologist*, *41*(10), 1040–1048.

Easterday, M. W., Lewis, D. R., & Gerber, E. M. (2014). Design-based research process: Problems, phases, and applications. In J. L. Polman, E. A. Kyza, D. K. O'Neill, I. Tabak, W. R. Penuel, A. S. Jurow, … L. D'Amico (Eds.), *Learning and Becoming in Practice: The International Conference of the Learning Sciences (ICLS) 2014* (pp. 317–324). Colorado, CO, USA: International Society of the Learning Sciences.

Easterday, M. W., Rees Lewis, D. G., & Gerber, E. M. (2018). The logic of design research. *Learning: Research and Practice*, *4*(2), 131–160.

Eccles, D. W., & Feltovich, P. J. (2008). Implications of domain-general "psychological support skills" for transfer of skill and acquisition of expertise. *Performance Improvement Quarterly*, *21*(1), 43–60.

Echeverría, A., Barrios, E., Nussbaum, M., Améstica, M., & Leclerc, S. (2012). The atomic intrinsic integration approach: A structured methodology for the design of games for the conceptual understanding of physics. *Computers & Education*, *59*(2), 806–816.

Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review*, *1*(1), 3–14.

Efklides, A. (2011). Interactions of metacognition with motivation and affect in self-regulated learning: The MASRL model. *Educational Psychologist*, *46*(1), 6–25.

Efklides, A. (2014). How does metacognition contribute to the regulation of learning? An integrative approach. *Psihologijske Teme*, *23*(1), 1–30.

Ertmer, P. A., & Newby, T. J. (1996). The expert learner: Strategic, self-regulated, and reflective. *Instructional Science*, *24*(1), 1–24.

Fallman, D. (2007). Why research-oriented design isn't design-oriented research: on the tensions between design and research in an implicit design discipline. *Knowledge, Technology & Policy*, *20*, 193–200.

Fessl, A., Bratic, M., & Pammer, V. (2014). Continuous learning with a quiz for stroke nurses. *International Journal of Technology Enhanced Learning*, *6*(3), 265–275.

Fiorella, L., & Mayer, R. E. (2012). Paper-based aids for learning with a computer-based game. *Journal of Educational Psychology*, *104*(4), 1074–1082.

Fiorella, L., & Vogel-Walcutt, J. J. (2011). Metacognitive prompting as a generalizable instructional tool in simulation-based training. In *Proceedings of the Human Factors and Ergonomics Society 55th Annual Meeting* (pp. 565–569). HFES.

Fishovitz, J., Crawford, G. L., & Kloepper, K. D. (2020). Guided heads-up: A collaborative game that promotes metacognition and synthesis of material while emphasizing higher-order thinking. *Journal of Chemical Education*, *97*(3), 681–688.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L.B. Resnick (Ed.), *The Nature of Intelligence* (pp. 231–235). Hillsdale, NJ: Erlbaum.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-development inquiry. *American Psychologist*, *34*(10), 906–911.

Foster, S. R., Esper, S., & Griswold, W. G. (2013). From competition to metacognition: designing diverse, sustainable educational games. In W. E. Mackay, S. A. Brewster, & S. Bodker (Eds.), *SIGCHI Conference on Human Factors in Computing Systems* (pp. 99–108). ACM.

Frayling, C. (1994). Research in art and design. *Royal College of Art Research Papers*, *1*(1).

Frazier, L. D., Schwartz, B. L., & Metcalfe, J. (2021). The MAPS model of self-regulation : Integrating metacognition, agency, and possible selves. *Metacognition and Learning*, *16*, 297–318.

Gagné, R. (1980). Learnable aspects of problem solving. *Educational Psychologist*, *15*, 84–92.

Gajadhar, B. J., De Kort, Y. A. W., & IJsselsteijn, W. A. (2008). Shared fun is doubled fun: Player enjoyment as a function of social setting. In P. Markopoulos, B. de Ruyter, W. A. IJsselsteijn, & D. Rowland (Eds.), *Fun and Games: International Conference on Fun and Games* (pp. 106–117). Springer-Verlag.

Gallagher, P. S., & Prestwich, S. H. (2013). Can game design be leveraged to enhance cognitive adaptability? *Electronic Journal of E-Learning*, *11*(1), 1–19.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation & Gaming*, *33*(4), 441–467.

Gascoine, L., Higgins, S., & Wall, K. (2016). The assessment of metacognition in children aged 4-16 years: A systematic review. *Review of Education*, *5*(1), 3–57.

Gee, J. P. (2004). Learning by design: Games as learning machines. *Interactive Educational Multimedia*, *8*(8), 15–23.

Graesser, A. C. (2017). Reflections on serious games. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 199–212).

Graham, S., & Harris, K. R. (2000). The role of self-regulation and transcription skills in writing and writing development. *Educational Psychologist*, *35*(1), 3–12.

Greene, J. A., & Azevedo, R. (2007). A theoretical review of Winne and Hadwin's model of self-regulated learning: New perspectives and directions. *Review of Educational Research*, *77*(3), 334–372.

Griffin, T. D., Wiley, J., & Salas, C. R. (2013). Supporting effective self-regulated learning: The critical role of monitoring. In R. Azevedo & V. Aleven (Eds.), *International Handbook of Metacognition and Learning Technologies* (pp. 19–35). New York: Springer.

Habgood, M. P. J. (2007). *The Effective Integration of Digital Games and Learning Content*. University of Nottingham.

Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *Journal of the Learning Sciences*, *20*(2), 169–206.

Hacker, D. J. (2017). The role of metacognition in learning via serious games. In R. Zheng & M. K. Gardner (Eds.), *Handbook of Research on Serious Games for Educational Applications* (pp. 19–40). Hershey, PA, USA: IGI Global.

Hacker, D. J., & Bol, L. (2019). Calibration and self-regulated learning: Making the connections. In J. Dunlosky & K. A. Rawson (Eds.), *The Cambridge Handbook of Cognition and Educations* (pp. 647–677). Cambridge, MA, USA: Cambridge University Press.

Hadwin, A. F., & Winne, P. H. (2001). CoNoteS2: A software tool for promoting Self-regulation. *Educational Research and Evaluation*, *7*(2–3), 313–334.

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior*, *54*, 170–179.

Hammond, K. R. (1998). Ecological validity: Then and now. Retrieved from https://www.albany.edu/cpr/brunswik/notes/essay2.html

Harrison, G. M., & Vallin, L. M. (2018). Evaluating the metacognitive awareness inventory using empirical factor-structure evidence. *Metacognition and Learning*, *13*(1), 15–38.

Hartman, H. J. (1998). Metacognition in teaching and learning: An introduction. *Instructional Science*, *26*(1/2), 1–3.

Hartman, H. J. (2001a). Developing students' metacognitive knowledge and strategies. In H. J. Hartman (Ed.), *Metacognition in Learning and Instruction: Theory, Research, and Practice* (pp. 33–68). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Hartman, H. J. (2001b). Teaching metacognitively. In H. J. Hartman (Ed.), *Metacognition in Learning and Instruction: Theory, Research, and Practice* (pp. 149–169). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Hattie, J. (2009). *Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement*. London: Routledge.

Hattie, J., Biggs, J., & Purdie, N. (1996). Effects of learning skills interventions on student learning: A meta-analysis. *Review of Educational Research*, *66*(2), 99–136.

Hevner, A. R. (2007). A three cycle view of design science research. *Scandinavian Journal of Information Systems*, *19*(2), 87–92.

Hevner, A. R., & Chatterjee, S. (2010). *Design Research in Information Systems*. New York, NY, USA: Springer.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, *28*(1), 75–105.

Hoffman, B., & Spatariu, A. (2008). The influence of self-efficacy and metacognitive prompting on math problem-solving efficiency. *Contemporary Educational Psychology*, *33*(4), 875–893.

Holleman, G. A., Hooge, I. T. C., Kemner, C., & Hessels, R. S. (2020). The "real-world approach" and its problems: A critique of the term ecological validity. *Frontiers in Psychology*, *11*, 721.

Höök, K., & Löwgren, J. (2012). Strong concepts: Intermediate-level knowledge in interaction. *ACM Transactions on Computer-Human Interaction*, *19*(3), 1–18.

Houde, S., & Hill, C. (1997). What do prototypes prototype? In M. Helander, T. Landauer, & P. Prabhu (Eds.), *Handbook of Human-Computer Interaction* (pp. 367–381). Amsterdam, The Netherlands: Elsevier.

Hoyningen-Huene, P. (1987). On the varieties of the distinction between the context of discovery and the context of justification. *Studies in History and Philosophy of Science*, *18*(4), 501–515.

Hoyningen-Huene, P. (2006). Context of discovery versus context justification and Thomas Kuhn. In J. Schickore & F. Steinle (Eds.), *Revisiting Discovery and Justification: Historical and Philosophical Perspectives on the Context Distinction* (pp. 119–131). Springer.

Hung, W., & Van Eck, R. (2010). Aligning problem solving and gameplay: A model for future research and design. In R. Van Eck (Ed.), *Interdisciplinary Models and Tools for Serious Games: Emerging Concepts and Future Directions* (pp. 227–263). IGI Global.

Hunicke, R. (2005). The case for dynamic difficulty adjustment in games. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology* (pp. 429–433).

Hunicke, R., LeBlanc, M., & Zubek, R. (2004). MDA: A formal approach to game design and game research. In *Proceedings of the AAAI Workshop on Challenges in Game AI* (pp. 1–5).

Jacobs, J. E., & Paris, S. G. (1987). Children's metacognition about reading: Issues in definition, measurement, and instruction. *Educational Psychologist*, *22*(3–4), 255–278.

Jansen, R. S., Leeuwen, A. Van, Janssen, J., Conijn, R., & Kester, L. (2020). Supporting learners' self-regulated learning in massive open online courses. *Computers & Education*, *146*, 103771.

Järvelä, S., Malmberg, J., Sobocinski, M., & Kirschner, P. A. (2021). Metacognition in collaborative learning. In U. Cress, C. Rosé, A. F. Wise, & J. Oshima (Eds.), *International Handbook of Computer-Supported Collaborative Learning* (pp. 281–294). Springer.

Johannesson, P., & Perjons, E. (2014). *An Introduction to Design Science*. Springer.

Johnson, C. I., Bailey, S. K. T., & Van Buskirk, W. L. (2017). Designing effective feedback messages in serious games and simulations: A research review. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 119–140). Springer.

Johnson, E. K. (2019). Waves: Scaffolding self-regulated learning to teach science in a whole-body educational game. *Journal of Science Education and Technology*, *28*, 133–151.

Kalyuga, S., & Plass, J. L. (2009). Evaluating and managing cognitive load in games. In R.E. Ferdig (Ed.), *Handbook of Research on Effective Electronic Gaming in Education* (pp. 719–737). IGI Global Press.

Kane, S., Lear, M., & Dube, C. M. (2014). Reflections on the role of metacognition in student reading and learning at higher education level. *Africa Education Review*, *11*(4), 512–525.

Kautzmann, T. R., & Jaques, P. A. (2019). Effects of adaptive training on metacognitive knowledge monitoring ability in computer-based learning. *Computers & Education*, *129*, 92–105.

Ke, F. (2008a). A case study of computer gaming for math: Engaged learning from gameplay? *Computers & Education*, *51*(4), 1609–1620.

Ke, F. (2008b). Alternative goal structures for computer game-based learning. *International Journal of Computer-Supported Collaborative Learning*, *3*(4), 429–445.

Ke, F. (2008c). Computer games application within alternative classroom goal structures: Cognitive, metacognitive, and affective evaluation. *Educational Technology Research and Development*, *56*(5–6), 539–556.

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In Richard E. Ferdig (Ed.), *Handbook of Research on Effective Electronic Gaming in Education* (pp. 1–32). IGI Global.

Ke, F. (2016). Designing and integrating purposeful learning in game play: a systematic review. *Educational Technology Research and Development*, *64*, 219–244.

Ke, F., Shute, V. J., Clark, K. M., & Erlebacher, G. (2019). An evolving design framework for game-based learning platforms. In F. Ke, V. Shute, K. M. Clark, & G. Erlebacher (Eds.), *Interdisciplinary Design of Game-Based Learning Platforms* (pp. 141–151). Springer.

Kenny, R. F., & Gunter, G. A. (2007). Endogenous fantasy-based serious games: Intrinsic motivation and learning. *International Journal of Social Sciences*, *2*(1), 8–13.

Khaled, R., Lessard, J., & Barr, P. (2018). Documenting trajectories in design space: A methodology for applied game design research. In *FDG18: Foundations of Digital Games*. New York, NY, USA: ACM.

Kihlstrom, J. F. (2021). Ecological validity and "ecological validity." *Perspectives on Psychological Science*, *16*(2), 466–471.

Kim, B. K., Park, H. S., & Baek, Y. (2009). Not just fun, but serious strategies: Using meta-cognitive strategies in game-based learning. *Computers and Education*, *52*(4), 800–810.

King, A. (1992). Facilitating elaborative learning through guided student-generated questioning. *Educational Psychologist*, *27*(1), 111–126.

Klauer, K. J. (1988). Teaching for learning-to-learn: A critical appraisal with some proposals. In *Annual Meeting of the American Educational Research Association*.

Kolarić, S., Beck, J., & Stolterman, E. (2020). On the hierarchical levels of design knowledge. In *Proceedings of the Design Society: DESIGN Conference* (pp. 51–60). Cambridge University Press.

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory Into Practice*, *41*(4), 212–218.

Krogh, P. G., & Koskinen, I. (2020). Drifting in four epistemic traditions. In *Drifting by Intention* (pp. 29–45). Cham, Switzerland: Springer.

Kuhn, D. (2000). Metacognitive development. *Current Directions in Psychological Science*, *9*(5), 178–181.

Kuhn, D., Garcia-Mila, M., Zohar, A., Andersen, C., White, S. H., Klahr, D., & Carver, S. M. (1995). Strategies of knowledge acquisition. *Monographs of the Society for Research in Child Development*, *60*(4), 1–157.

Lameras, P., Arnab, S., Dunwell, I., Stewart, C., Clarke, S., & Petridis, P. (2017). Essential features of serious games design in higher education: Linking learning attributes to game mechanics. *British Journal of Educational Technology*, *48*(4), 972–994.

Lee, H. W., Lim, K. Y., & Grabowski, B. L. (2010). Improving self-regulation, learning strategy use, and achievement with metacognitive feedback. *Educational Technology Research and Development*, *58*, 629–648.

Lee, J., & Choi, H. (2017). What affects learner's higher-order thinking in technology-enhanced learning environments? The effects of learner factors. *Computers & Education*, *115*, 143–152.

Lim, T., Louchart, S., Suttie, N., Ritchie, J. M., Aylett, R. S., Stanescu, I. A., … Moreno-Ger, P. (2013). Strategies for effective digital games development and implementation. In Y. Baek & N. Whitton (Eds.), *Cases on digital game-based learning: Methods, models, and strategies* (pp. 168–198). IGI Global.

Lin, X. (2001). Designing metacognitive activities. *Educational Technology Research and Development*, *49*(2), 23–40.

Lins de Holanda Coelho, G., Hanel, P. H. P., & Wolf, L. J. (2018). The very efficient assessment of need for cognition: Developing a six-item version. *Assessment*, *27*(8), 1870–1885.

Liu, S., & Liu, M. (2020). The impact of learner metacognition and goal orientation on problem-solving in a serious game environment. *Computers in Human Behavior*, *102*, 151–165.

Löwgren, J., Larsen, H. S., & Hobye, M. (2013). Towards programmatic design research. *Designs for Learning*, *6*(1–2), 80–100.

Malone, T. W. (1980). *What makes things fun to learn? A study of intrinsically motivating computer games*. Stanford University.

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science*, *4*, 333–369.

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R. E. Snow & M. J. Farr (Eds.), *Aptitude, Learning, and Instruction* (pp. 223–253). Hillsdale, NJ, USA: Lawrence Erlbaum Associates.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266.

Martinez-Garza, M. M., & Clark, D. B. (2017). Two systems, two stances: A novel theoretical framework for model-based learning in digital games. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 37–58). Springer.

Marzano, R. J., & Kendall, J. S. (2007). *The New Taxonomy of Educational Objectives* (2nd ed.). Thousand Oaks: Corwin Press.

Maton, K. (2009). Cumulative and segmented learning: exploring the role of curriculum structures in knowledge-building. *British Journal of Sociology of Education*, *30*(1), 43–57.

Mayer, R. E. (2014a). *Computer Games for Learning: An Evidence-Based Approach*. Cambridge, MA, USA: MIT Press.

Mayer, R. E. (2014b). Examples of three genres of game research. In *Computer Games for Learning: An Evidence-Based Approach*. Cambridge, MA, USA: The MIT Press.

Mayer, R. E. (2016). The role of metacognition in STEM games and simulations. In H. F. O'Neil, E. L. Baker, & R. S. Perez (Eds.), *Using Games and Simulations for Teaching and Assessment: Key Issues* (pp. 183–205). New York: Routledge.

McCarthy, K. S., Jacovina, M. E., Snow, E. L., Guerrero, T. A., & McNamara, D. S. (2017). iSTART therefore I understand: But metacognitive supports did not enhance comprehension gains. In E. André, R. Baker, X. Hu, M. M. T. Rodrigo, & B. Du Boulay (Eds.), *International Conference on Artificial Intelligence in Education* (pp. 201–211). Springer.

McCormick, C. B., Dimmitt, C., & Sullivan, F. R. (2013). Metacognition, learning, and instruction. In W. M. Reynolds, G. E. Miller, & I. B. Weiner (Eds.), *Handbook of Psychology, Volume 7: Educational Psychology* (2nd ed., pp. 69–97). Wiley.

McKenney, S., & Reeves, T. C. (2012). *Conducting Educational Design Research*. Abingdon, UK: Routledge.

McNamara, D. S. (2009). Self-explanation and metacognition. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of Metacognition in Education* (pp. 60–81). Routledge.

McQuiggan, S., & Hoffmann, K. (2008). Examining self-regulated learning in a narrative-centered learning environment: An inductive approach to modeling metacognitive monitoring. *Proceedings of the ITS'08 Workshop on Metacognition and Self-Regulated Learning in Educational Technologies*, 51–60.

Meijer, J., Sleegers, P., Elshout-Mohr, M., Van Daalen-Kapteijns, M., Meeus, W., & Tempelaar, D. (2013). The development of a questionnaire on metacognition for students in higher education. *Educational Research*, *55*(1), 31–52.

Merriënboer, J. J. G. Van, & Bruin, A. B. H. De. (2019). Cue-based facilitation of self-regulated learning: A discussion of multidisciplinary innovations and strategies. *Computers in Human Behavior*, *100*, 384–391.

Molenaar, I., Boxtel, C. A. M. Van, & Sleegers, P. J. C. (2011). Metacognitive scaffolding in an innovative learning arrangement. *Instructional Science*, *39*(6), 785–803.

Moser, S., Zumbach, J., & Deibl, I. (2017). The effect of metacognitive training and prompting on learning success in simulation-based physics learning. *Science Education*, *101*, 944–967.

Moshman, D. (2018). Metacognitive theories revisited. *Educational Psychology Review*, *30*, 599–606.

Muijs, D., Kyriakides, L., Werf, G. Van Der, Creemers, B., Timperley, H., & Earl, L. (2014). State of the art – Teacher effectiveness and professional learning. *School Effectiveness and School Improvement*, *25*(2), 231–256.

Nadolny, L., Valai, A., Cherrez, N. J., Elrick, D., Lovett, A., & Nowatzke, M. (2020). Examining the characteristics of game-based learning: A content analysis and design framework. *Computers & Education*, *156*, 103936.

Narciss, S., Proske, A., & Koerndle, H. (2007). Promoting self-regulated learning in web-based learning environments. *Computers in Human Behavior*, *23*(3), 1126–1144.

Nebel, S., Schneider, S., Beege, M., & Rey, G. D. (2017). Leaderboards within educational videogames: The impact of difficulty, effort and gameplay. *Computers & Education*, *113*, 28–41.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. In *The Psychology of Learning and Motivation* (pp. 125–173). Academic Press.

Nelson, T. O., & Narens, L. (1994). Why investigate metacognition? In J. Metcalfe & A. P. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 1–25). Cambridge, MA, USA: MIT Press.

Nerial. (2016). Reigns. Devolver Digital.

Nietfeld, J., & Shores, L. R. (2011). Self-regulation within game-based learning environments. In L. Annetta & S. C. Bronack (Eds.), *Serious Educational Game Assessment* (pp. 19–42). Sense Publishers.

Novak, K. (2017). It takes a guild – Social metacognition and collaborative creation of a learning organization: Massively multiplayer online game. In A. Stricker, C. Calongne, B. Truman, & F. Arenas (Eds.), *Integrating an Awareness of Selfhood and Society into Virtual Learning* (pp. 198–224). IGI Global.

O'Rourke, E., Haimovitz, K., Ballwebber, C., Dweck, C. S., & Popović, Z. (2014). Brain Points: A growth mindset incentive structure boosts persistence in an Educational game. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 3339–3348).

Oguz, A., & Sahin, I. (2011). Literature Review on Metacognition and its Measurement. *Procedia Social and Behavioral Sciences*, *15*, 3731–3736.

Ohtani, K., & Hisasaka, T. (2018). Beyond intelligence: a meta-analytic review of the relationship among metacognition, intelligence, and academic performance. *Metacognition and Learning*, *13*, 179–212.

Osman, M. E., & Hannafin, M. J. (1992). Metacognition research and theory: Analysis and implications for instructional design. *Educational Technology Research and Development*, *40*(2), 83–99.

Ouellette, M. A. (2019). "I'm controlling and composing": The role of metacognition in The Incredible Machine. *InVisible Culture*, *30*.

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology*, *8*, 422.

Panadero, E., & Järvelä, S. (2015). Socially shared regulation of learning: A review. *European Psychologist*, *20*(3), 190–203.

Pannese, L., Morosini, D., Moore, A., & Pammer, V. (2012). User models and affective metacognitive scaffolding for adaptive games. In P. Felicia (Ed.), *Proceedings of the 6th European Conference on Games Based Learning* (pp. 649–652). Cork, Ireland: Academic Conferences.

Paras, B., & Bizzocchi, J. (2005). Game, motivation, and effective learning: An integrated model for educational game design. In *Proceedings of DiGRA 2005 Conference: Changing Views: Worlds in Play.*

Paris, S. G., & Winograd, P. (1990). How metacognition can promote academic learning and instruction. In B. F. Jones & L. Idol (Eds.), *Dimensions of Thinking and Cognitive Instruction* (pp. 15–51). Routledge.

Pawar, S., Tam, F., Plass, J. L., & Pawar, S. (2019). Emerging design factors in game-based learning: Emotional design, musical score, and game mechanics design. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 347–365). Cambridge, MA, USA: MIT Press.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems ISSN:*, *24*(3), 45–77.

Peña-Ayala, A. (Ed.). (2015). *Metacognition: Fundaments, Applications, and Trends*. Springer.

Pieschl, S. (2009). Metacognitive calibration — An extended conceptualization and potential applications. *Metacognition and Learning*, *4*, 3–31.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts & P. R. Pintrich (Eds.), *Handbook of Self-Regulated Learning* (pp. 13–39). Academic Press.

Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching, and assessing. *Theory into Practice*, *41*(4), 219–225.

Pintrich, P. R., Smith, D. A. F., Garcia, T., & McKeachie, W. J. (1993). Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ). *Educational and Psychological Measurement*, *53*, 801–813.

Pintrich, P. R., Wolters, C. A., & Baxter, G. P. (2000). Assessing metacognition and self-regulated learning. In G. Schraw & J. C. Impara (Eds.), *Issues in the Measurement of Metacognition*. Lincoln, NE, USA: Buros Center for Testing.

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist*, *50*(4), 258–283.

Plass, J. L., Homer, B. D., Mayer, R. E., & Kinzer, C. K. (2019). Theoretical foundations of game-based and playful learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 3–24). Cambridge, MA, USA: The MIT Press.

Plomp, T. (2013). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *Educational Design Research* (pp. 10–51). Enschede: SLO.

Prensky, M. (2003). Digital game-based learning. *Computers in Entertainment*, *1*(1), 21–24.

Proulx, J.-N., Romero, M., & Arnab, S. (2017). Learning mechanics and game mechanics under the perspective of self- determination theory to foster motivation in digital game based learning. *Simulation & Gaming*, *48*(1), 81–97.

Przybylski, A. K., Rigby, C. S., & Ryan, R. M. (2010). A motivational model of video game engagement. *Review of General Psychology*, *14*(2), 154–166.

Puustinen, M., & Pulkkinen, L. (2001). Models of self-regulated learning: A review. *Scandinavian Journal of Educational Research*, *45*(3), 269–286.

Raybourn, E. M. (2009). Intercultural competence game that fosters metacognitive agility and reflection. In A. A. Ozok & P. Zaphiris (Eds.), *Online Communities* (pp. 603–612). Springer-Verlag.

Redström, J. (2011). Some notes on program/experiment dialectics. In *Nordic Design Research Conference*. Helsinki: Aalto University.

Rhodes, M. G. (2019). Metacognition. *Teaching of Psychology*, *46*(2), 168–175.

Ricker, A. A., & Richert, R. A. (2021). Digital gaming and metacognition in middle childhood. *Computers in Human Behavior*, *115*, 106593.

Rieber, L. P. (1996). Seriously considering play. *Eudcational Technology Research and Development*, *44*(2), 43–58.

Roll, I., Aleven, V., McLaren, B. M., Ryu, E., Baker, R. S. J. d., & Koedinger, K. R. (2006). The help tutor: Does metacognitive feedback improve students' help-seeking actions, skills and learning? In *International Conference on Intelligent Tutoring Systems* (pp. 360–369). Springer.

Romainville, M. (1994). Awareness of cognitive strategies: The relationship between university students' metacognition and their performance. *Studies in Higher Education*, *19*(3), 359–366.

Romero, M., Usart, M., Ott, M., Earp, J., De Freitas, S., & Arnab, S. (2012). Learning through playing for or against each other? Promoting collaborative learning in digital game based learning. In *European Conference on Information Systems 2012 Proceedings*.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68–78.

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion*, *30*(4), 347–363.

Sabourin, J. L., Shores, L. R., Mott, B. W., & Lester, J. C. (2013). Understanding and predicting student self-regulated learning strategies in game-based learning environments. *International Journal of Artificial Intelligence in Education*, *23*(1–4), 94–114.

Salen, K., & Zimmerman, E. (2004). *Rules of Play: Game Design Fundamentals*. Cambridge, MA, USA: MIT Press.

Sanchez, E. (2017). Competition and collaboration for game-based learning: A case study. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 161–184). Springer.

Sandoval, W. A. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist*, *39*(4), 213–223.

Sandoval, W. A. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*, *23*(1), 18–36.

Sandoval, W. A., & Bell, P. (2004). Design-based research methods for studying learning in context. *Educational Psychologist*, *39*(4), 199–201.

Scheel, A. M., Tiokhin, L., Isager, P. M., & Lakens, D. (2021). Why hypothesis testers should spend less time testing hypotheses. *Perspectives on Psychological Science*, *16*(4), 744–755.

Schell, J. (2019). *The Art of Game Design - A Book of Lenses*. AK Peters/CRC Pres.

Schellings, G., & Van Hout-Wolters, B. H. A. M. (2011). Measuring strategy use with self-report instruments: Theoretical and empirical considerations. *Metacognition and Learning*, *6*, 83–90.

Schneider, W. (2008). The development of metacognitive knowledge in children and adolescents: Major trends and implications for education. *Mind, Brain, and Education*, *2*(3), 114–121.

Schoenfeld, A. H. (1987). What’s all the fuss about metacognition? In A. H. Schoenfeld (Ed.), *Cognitive Science and Mathematics Education* (pp. 189–215). Lawrence Erlbaum Associates.

Schoenfeld, A. H. (2009). Instructional research and the improvement of practice. In J. D. Bransford, D. J. Stipek, N. . Vye, L. M. Gomez, & D. Lam (Eds.), *The Role of Research in Educational Improvement* (pp. 161–188). Cambridge, MA, USA: Harvard Education Press.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. Basic Books.

Schraw, G. (1998). Promoting general metacognitive awareness. *Instructional Science*, *26*, 113–125.

Schraw, G. (2009). Measuring metacognitive judgments. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of Metacognition in Education* (pp. 415–429). New York, NY, USA: Routledge.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*(1–2), 111–139.

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology*, *19*, 460–475.

Schraw, G., Horn, C., Thorndike-Christ, T., & Bruning, R. (1995). Academic goal orientations and student classroom achievement. *Contemporary Educational Psychology*, *20*(3), 359–368.

Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review*, *7*(4), 351–371.

Schwarzer, R., & Jerusalem, M. (1995). Generalized self-efficacy scale. In J. Weinman, S. Wright, & M. Johnston (Eds.), *Measures in health psychology: A user's portfolio. Causal and control beliefs* (pp. 35–37).

Schwonke, R., Ertelt, A., Otieno, C., Renkl, A., Aleven, V., & Salden, R. J. C. M. (2013). Metacognitive support promotes an effective use of instructional resources in intelligent tutoring. *Learning and Instruction*, *23*(1), 136–150.

Scoresby, J., & Shelton, B. E. (2014). Reflective redo from the point of error: Implications for after action review. *Simulation & Gaming*, *45*(4–5), 666–696.

Shelton, B. E., & Scoresby, J. (2011). Aligning game activity with educational goals: Following a constrained design approach to instructional computer games. *Educational Technology Research and Development*, *59*(1), 113–138.

Shimamura, A. P. (2008). A neurocognitive approach to metacognitive monitoring and control. In J. Dunlosky & R. A. Bjork (Eds.), *Handbook of Memory and Metamemory: Essays in Honor of Thomas O. Nelson* (pp. 373–390). New York: Psychology Press.

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, *64*(2), 489–528.

Slussareff, M., Braad, E., Wilkinson, P., & Strååt, B. (2016). Games for learning. In R. Dorner, S. Gobel, M. D. Kickmeier-Rust, M. Masuch, & K. Zweig (Eds.), *Entertainment Computing and Serious Games*. Springer.

Snow, E. L. (2015). *Promoting Self-Regulation and Metacognition through the Use of Online Trace Data*.

Snow, E. L., Jacovina, M. E., & McNamara, D. S. (2015). Promoting metacognition within a game-based environment. In *International Conference on Artificial Intelligence in Education* (pp. 864–867). Springer.

Snow, E. L., McNamara, D. S., Jacovina, M. E., Allen, L. K., Johnson, A. M., Perret, C. A., … Weston, J. L. (2015). Promoting metacognitive awareness within a game-based intelligent tutoring system. In C. Conati, N. Heffernan, A. Mitrovic, & M. Verdejo (Eds.), *AIED 2015: Artificial Intelligence in Education* (pp. 786–789).

Squire, K. D. (2006). From content to context: Videogames as designed experience. *Educational Researcher*, *35*(8), 19–29.

Steiner, C. M., Kickmeier-Rust, M. D., Mattheiss, E., Göbel, S., & Albert, D. (2012). Balancing on a high wire: Adaptivity, a key factor of future learning games. In M. D. Kickmeier-rust & D. Albert (Eds.), *An Alien's Guide to Multi-Adaptive Educational Computer Games*. Informing Science Press.

Steinkuehler, C., & Tsaasan, A. M. (2019). Sociocultural foundations of game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 177-). Cambridge, MA, USA: The MIT Press.

Sternberg, R. J. (2001). Metacognition, abilities, and developing expertise: What makes an expert student? In H. J. Hartman (Ed.), *Metacognition in Learning and Instruction* (pp. 274–260). Springer.

Stokes, D. (1997). *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Institution Press.

Sun-Lin, H.-Z. S., & Chiou, G.-F. (2017). Effects of comparison and game-challenge on sixth graders' algebra variable learning achievement, learning attitude, and meta-cognitive awareness. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(6), 2627–2644.

Sung, H.-Y., Hwang, G. J., Lin, C. J., & Hong, T. W. (2017). Experiencing the analects of Confucius: An experiential game-based learning approach to promoting students' motivation and conception of learning. *Computers & Education*, *110*, 143–153.

Taito. (1978). Space Invaders. Atari.

Tang, Y., Shetty, S., Bielefeldt, T., Jahan, K., Henry, J., & Hargrove, S. K. (2012). Sustain City - A cyberinfrastructure-enabled game system for science and engineering design. *Journal of Computational Science Education*, *3*(1).

Tang, Y., Shetty, S., & Chen, X. (2012). Educational effectiveness of virtual reality games promoting metacognition. In *ASEE Annual Conference and Exposition*. American Society for Engineering Education.

Tarricone, P. (2011). *The Taxonomy of Metacognition*. Hove, East Sussex, UK: Psychology Press.

Taub, M., Azevedo, R., Bradbury, A. E., & Mudrick, N. V. (2020). Self-regulation and reflection during game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 239–262). Cambridge, MA, USA: MIT Press.

Taub, M., Mudrick, N. V., Azevedo, R., Millar, G. C., Rowe, J. P., & Lester, J. (2016). Using multi-level modeling with eye-tracking data to predict metacognitive monitoring and self-regulated learning with Crystal Island. In A. Micarelli, J. Stamper, & K. Panourgia (Eds.), *Intelligent Tutoring Systems (ITIS 2016)* (pp. 240–246). Cham, Switzerland: Springer.

Ter Vrugte, J., & De Jong, T. (2017). Self-explanations in game-based learning: from tacit to transferable knowledge. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 141–159). Springer.

Ter Vrugte, J., De Jong, T., Vandercruysse, S., Wouters, P., Van Oostendorp, H., & Elen, J. (2015). How competition and heterogeneous collaboration interact in prevocational game-based mathematics education. *Computers & Education*, *89*, 42–52.

Tremblay, M. A., Blanchard, M., Taylor, S., Pelletier, L. G., & Villeneuve, M. (2009). Work extrinsic and intrinsic motivation scale: Its value for psychology research. *Canadian Journal of Behavioural Science*, *41*(4), 213–226.

Tüysüz, C. (2009). Effect of the computer based game on pre-service teachers' achievement, attitudes, metacognition and motivation in chemistry. *Scientific Research and Essays*, *4*(8), 780–790.

Usart, M., Romero, M., & Almirall, E. (2011). Impact of the feeling of knowledge explicitness in the learners' participation and performance in a collaborative game based learning activity. In M. Ma, M. Fradinho Oliveira, & J. Madeiras Pereira (Eds.), *Serious Games Development and Applications* (pp. 23–35). Springer.

Van den Akker, J., Branch, R. M., Gustafson, K., Nieveen, N., & Plomp, T. (1999). *Design Approaches and Tools in Education and Training*. (J. Van den Akker, R. M. Branch, K. Gustafson, N. Nieveen, & T. Plomp, Eds.). Springer.

Van Der Meij, H., Leemkuil, H., & Li, J. L. (2013). Does individual or collaborative self-debriefing better enhance learning from games? *Computers in Human Behavior*, *29*(6), 2471–2479.

Van Eck, R., & Hung, W. (2010). A taxonomy and framework for designing educational games to promote problem solving. In *Videogame Cultures & the Future of Interactive Entertainment Annual Conference of the Inter-Disciplinary.net Group*. Oxford, United Kingdom.

Van Oostendorp, H., & Wouters, P. (2017). Narration-based techniques to facilitate game-based learning. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 103–117). Springer.

Van Overschelde, J. P. (2008). Metacognition: Knowing about knowing. In J. Dunlosky & R. A. Bjork (Eds.), *Handbook of Metamemory and Memory* (pp. 44–71). New York: Psychology Press.

Van Staalduinen, J.-P., & De Freitas, S. (2011). A game-based learning framework linking game design and learning outcomes. In M. S. Khyne (Ed.), *Learning to Play: Exploring the Future of Education with Video Games* (pp. 29–54). New York: Peter Lang.

Vandercruysse, S., & Elen, J. (2017). Towards a game-based learning instructional design model focusing on integration. In P. Wouters & H. van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 17–35).

Veenman, M. V. J. J. (2011a). Alternative assessment of strategy use with self-report instruments: A discussion. *Metacognition and Learning*, *6*, 205–211.

Veenman, M. V. J. J. (2011b). Learning to self-monitor and self-regulate. In R. E. Mayer & P. Alexander (Eds.), *Handbook of Research on Learning and Instruction* (pp. 197–218). New York: Routledge.

Veenman, M. V. J. J., Elshout, J. J., & Busato, V. K. (1994). Metacognitive mediation in learning with computer-based simulations. *Computers in Human Behavior*, *10*, 93–106.

Veenman, M. V. J. J., Kerseboom, L., & Imthorn, C. (2000). Test anxiety and metacognitive skillfulness: Availability versus production deficiencies. *Anxiety, Stress, and Coping*, *13*, 391–412.

Veenman, M. V. J. J., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and Individual Differences*, *15*, 159–176.

Veenman, M. V. J. J., Van Hout-Wolters, B. H. A. M., & Afflerbach, P. (2006). Metacognition and learning: conceptual and methodological considerations. *Metacognition and Learning*, *1*, 3–14.

Verpoorten, D., Castaigne, J.-L., Westera, W., & Specht, M. (2014). A quest for meta-learning gains in a physics serious game. *Education and Information Technologies*, *19*, 361–374.

Vlachopoulos, D., & Makri, A. (2017). The effect of games and simulations on higher education: a systematic literature review. *International Journal of Educational Technology in Higher Education*, *14*(1), 22.

Wang, C. Y. (2015). Exploring general versus task-specific assessments of metacognition in university chemistry students: A multitrait–multimethod analysis. *Research in Science Education*, *45*(4), 555–579.

Wang, M. C., Haertel, G. D., & Walberg, H. J. (1990). What influences learning? A content analysis of review literature. *Journal of Educational Research*, *84*(1).

Wensveen, S., & Matthews, B. (2014). Prototypes and prototyping in design research. In P. A. Rodgers & J. Yee (Eds.), *The Routledge Companion to Design Research* (pp. 262–276). Abingdon, UK: Taylor & Francis.

White, B. Y., & Frederiksen, J. (2005). A theoretical framework and approach for fostering metacognitive development. *Educational Psychologist*, *40*(4), 211–223.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*(1), 3–118.

Winne, P. H. (2010). Bootstrapping learner's self-regulated learning. *Psychological Test and Assessment Modeling*, *52*(4), 472–490.

Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in Educational Theory and Practice* (pp. 277–304). Lawrence Erlbaum Associates.

Winne, P. H., & Hadwin, A. F. (2013). nStudy: Tracing and supporting self-regulated learning in the internet. In R. Azevedo & V. Aleven (Eds.), *International Handbook of Metacognition and Learning Technologies* (pp. 293–208). Springer.

Winne, P. H., & Jamieson-Noel, D. (2002). Exploring students' calibration of self reports about study tactics and achievement. *Contemporary Educational Psychology*, *27*, 551–572.

Winne, P. H., & Nesbit, J. C. (2009). Supporting self-regulated learning with cognitive tools. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of Metacognition in Education* (pp. 271–289). Routledge.

Winne, P. H., Nesbit, J. C., Kumar, V., Hadwin, A. F., Lajoie, S. P., Azevedo, R., & Perry, N. E. (2006). Supporting self-regulated learning with gStudy software: The learning kit project. *Technology, Instruction, Cognition & Learning*, *3*, 105–113.

Winters, F. I., Greene, J. A., & Costich, C. M. (2008). Self-regulation of learning within computer-based learning environments: A critical analysis. *Educational Psychology Review*, *20*(4), 429–444.

Wouters, P., Van Nimwegen, C., Van Oostendorp, H., & Van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265.

Wouters, P., & Van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education*, *60*(1), 412–425.

Wouters, P., & Van Oostendorp, H. (2017). Overview of instructional techniques to facilitate learning and motivation of serious games. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 1–16). Cham, Switzerland: Springer.

Yeh, Y., Chen, M., Hung, P., & Hwang, G. (2010). Optimal self-explanation prompt design in dynamic multi-representational learning environments. *Computers & Education*, *54*(4), 1089–1100.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., … Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research*, *82*(1), 61–89.

Zainuddin, Z., Kai, S., Chu, W., Shujahat, M., & Jacqueline, C. (2020). The impact of gamification on learning and instruction: A systematic review of empirical evidence. *Educational Research Review*, *30*.

Zepeda, C. D., Hlutkowsky, C. O., Partika, A. C., & Nokes-Malach, T. J. (2018). Identifying teachers' supports of metacognition through classroom talk and its relation to growth in conceptual learning. *Journal of Educational Psychology*, *111*(3), 522–541.

Zepeda, C. D., Richey, J. E., Ronevich, P., & Nokes-Malach, T. J. (2015). Direct instruction of metacognition benefits adolescent science learning, transfer, and motivation: An in vivo study. *Journal of Educational Psychology*, *107*(4), 954–971.

Zheng, L., Li, X., Zhang, X., & Sun, W. (2019). The effects of group metacognitive scaffolding on group metacognitive behaviors, group performance, and cognitive load in computer-supported collaborative learning. *The Internet and Higher Education*, *42*(19), 13–24.

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology*, *81*(3), 329–339.

Zimmerman, B. J. (1990). Self-regulating academic learning and achievement: The emergence of a social cognitive perspective. *Educational Psychology Review*, *2*, 173–201.

Zimmerman, B. J., & Campillo, M. (2003). Motivating self-regulated problem solvers. In J. E. Davidson & R. J. Sternberg (Eds.), *The Psychology of Problem Solving* (pp. 233–262). Cambridge University Press.

Zimmerman, B. J., & Schunk, D. H. (1989). *Self-Regulated Learning and Academic Achievement: Theory, Research, and Practice*. New York: Springer-Verlag.

Zimmerman, B. J., & Tsikalas, K. E. (2005). Can computer-based learning environments (CBLEs) be used as self-regulatory tools to enhance learning? *Educational Psychologist*, *40*(4), 267–271.

Zimmerman, J., & Forlizzi, J. (2008). The role of design artifacts in design theory construction. *Artifact*, *II*(1), 41–45.

Zimmerman, J., & Forlizzi, J. (2014). Research through design in HCI. In J. Olson & W. Kellogg (Eds.), *Ways of Knowing in HCI*. New York: Springer.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 493–502).

Zumbach, J., Rammerstorfer, L., & Deibl, I. (2020). Cognitive and metacognitive support in learning with a serious game about demographic change. *Computers in Human Behavior*, *103*, 120–129.

Glossary

design research: The systematic and iterative study of designed interventions and through designed interventions to inform the effective solutions of practical problems.

game: A system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome (in general), with specific learning goals (specific to game-based learning).

game-based learning (GBL): An interactive form of learning where gameplay is designed to help learners achieve specific learning objectives through interaction with the game-based learning environment.

game-based learning environment (GBLE): The digital and interactive environment that facilitates game-based learning and that may contain game elements and instructional elements.

gameplay: The way players play and experience a game through the repeated activities, or sets of activities, performed throughout the game.

intermediate-level design knowledge: Design knowledge that is more abstracted than particular instantiation but less general than a theory.

learning process: The active, intentional, and directed effort of learners exerted towards achievement of a set of learning goals.

learning strategy: The mental tactics employed to facilitate acquisition of knowledge or skill.

metacognition: A learner's conscious understanding of how to use declarative, procedural, and conditional metacognitive knowledge about oneself, learning tasks, and strategies, to metacognitively plan, monitor, and evaluate learning in practice.

metacognitive instruction: The direct and explicit teaching of (aspects of) metacognition.

metacognitive knowledge: The knowledge a person has about learning. Metacognitive knowledge is about persons, tasks, and strategies.

metacognitive mechanism: A mechanism within a learning environment that is designed to promote metacognition in learners, for example, a metacognitive question prompt or strategy cue.

metacognitive process: A process that mediates between the cognitive level of learning and the metacognitive level through monitoring and controlling the cognitive operations involved in learning.

metacognitive skills: Metacognitive processes used by learners to apply metacognitive knowledge to learning, emphasizing that metacognitive processes can be improved through repeated practice.

metacognitive support: The indirect support of (aspects of) metacognition during learning.

metacognitive theory: The metacognitive knowledge about persons, tasks, and strategies, as a set of beliefs held by an individual that informs their conception of learning.

metacognitive training: The metacognitive instruction and/or metacognitive support aimed at promoting and improving metacognition in learners.

monitoring learning: The metacognitive process of inspecting learning and informing judgments of performance, progress and effectivity.

regulation of learning: The process of making informed adjustments to learning in response to judgments of learning.

self-regulated learning (SRL): A type of learning that characterizes learners as active participants in their own learning process who study how they learn and how learning helps them to achieve their goals.

Summary

One of the most influential determinants of efficient and effective learning is metacognition: the knowledge a learner has about how they learn, and the skills to use that knowledge to monitor and regulate learning. As not all learners within higher education are equally or sufficiently apt in metacognition, providing metacognitive training is a very effective way of improving current and future learning skills and, in turn, learning performance.

Metacognitive training must be active (for learners to understand and be able to apply metacognition to learning) as well as engaging (for learners to put in the additional effort over a longer period of time). In this dissertation, we examine how *game-based learning* (GBL), as a technique to harness learning and motivation in a self-contained *game-based learning environment* (GBLE), can be leveraged for metacognitive training. The educational context for this dissertation is higher education in The Netherlands, where metacognitive knowledge and skills involved in self-regulated learning are often implicitly expected of students, but seldomly explicitly taught within study programs.

The main research question for this dissertation is: How can we design effective game-based learning environments to improve metacognition of learners in higher education? With our research we seek to achieve two objectives:

(i) *to gather and synthesize design knowledge*, across different disciplines and from existent and new research, to further the understanding of the design of game-based learning environments for metacognition; and

(ii) *to apply and evaluate design knowledge* in real-world educational settings, through the conceptualization and construction of prototypes, and by collecting insights about and from students using them.

The overarching research methodology used throughout this dissertation is design research: the systematic and iterative study *of* and *through* designed interventions to inform the design of an effective solution. Design research provides synergy between knowledge contributions and practical contributions, accommodates an interdisciplinary integration of concepts and methods, and provides ways of generalizing findings beyond a specific instantiation. Through analysis of existent work, through design and construction of prototypes, and through design experiments within real-world educational settings, mixed methods are used to gather insights on the design of GBLEs for metacognitive training.

The first part of this dissertation concerns the *Analysis and Exploration* phase, with the objective of gathering and synthesizing current insights on training metacognition, designing GBLEs, and their combination in the design of GBLEs for metacognition.

We conducted a qualitative review of current literature on the design of GBLEs that promote metacognition in learners. Our analysis of the GBLE-designs from the selected studies identified key mechanisms for promoting metacognition within GBLEs, three types of integration of metacognitive content with gameplay, and a number of preliminary design implications. However, we also found that research in this area is predominantly reported as case-by-case findings. The limited ways in which GBLE-designs can be compared across such different studies stands in the way of advancing insights across this field and, correspondingly, there is a lack of design-informing work based on a combination of empirical and theoretical insights.

To improve the way in which the designs of GBLEs for training metacognition can be communicated, we developed a design framework. The *Design Framework for Metacognition in GBL* is derived from existing literature and cases as identified in the literature review, and further elaborated through a formative expert evaluation. For metacognitive instruction, for gameplay, and for the integration of both, the resulting framework defines specific design dimensions that indicate the relevant areas in which informed design-decisions are likely to affect learners' metacognition. As such, this framework aids specification of designs, structured comparisons between different designs, and a more focused research effort in identifying specific design guidelines for metacognition in GBL.

The second part of this dissertation concerns the phases of *Design and Construction* and *Evaluation and Reflection*, with the objective of applying and elaborating design knowledge through the design, construction, and evaluation of GBLEs for training metacognition.

We first focused on the instructional dimensions of the framework and designed a digital tool to support metacognition through self-explication of learners' otherwise implicit conceptions of learning. Through a pre-test/post-test quasi-experiment with a comparison group we examined a detached approach to metacognitive training, where digital metacognitive support is offered via a digital tool in parallel to ongoing domain-specific training. We compared effects between domain-specific and domain-general metacognitive support, and evaluated how learners use and perceive the use of such a tool. We found that self-explication is an effective mechanism to support and improve metacognition and confirmed the effectiveness of detached metacognitive support. While only domain-specific metacognitive support was found to be effective, quantitative and qualitative analysis warrant further research into domain-general and detached metacognitive support. However, we also found that learners with low *a priori* metacognition were particularly likely to not make use of the available support: the group that can benefit most from metacognitive training does not see the added value of it.

To address this issue by making metacognitive training easier and more appealing to use, we then focused on the gameplay dimensions of the framework and the integration of metacognitive training with gameplay. We formalized and formulated known design principles within the dimensions of the design framework. As such, the descriptive design framework is augmented with increasingly prescriptive design knowledge. We conducted a series of design experiments within real-world educational settings to articulate, apply, and evaluate the design knowledge as applied to the design of concrete GBLEs. Each design experiment addresses a particular configuration of the design dimensions of the framework. From these design experiments we were able to synthesize findings into further recommendations for the design of GBLEs for training metacognition.

GBLEs to train metacognition must be carefully designed to effectively promote metacognition and learning, while at the same time inciting and sustaining engagement in learners so they keep making use of it. We found that the design of such GBLEs is a complex endeavor, where many design decisions must be made while little guidance is available. Our work has identified and synthesized relevant design knowledge to provide such guidance. Together, the design framework dimensions and the accompanying design principles, as well as the different integration types and metacognitive mechanisms provide the basis for more informed and more deliberate designs of GBLEs. Furthermore, we provide an initial design process that incorporates these different types of design knowledge.

However, further theoretical and empirical work is needed to advance insights into game-based metacognitive training. For this purpose, the dimensions of the framework can serve as a research agenda by indicating where design knowledge is lacking or needs empirical verification. We also put forward a possible theoretical model that could help to improve understanding of the design of game-based metacognitive training. The ideas, design knowledge, prototypes, and general thoughts put forward in this work form a solid foundation for such relevant future work.

Publications and Presentations

The following publications and presentations resulted from the work described in this dissertation:

Braad, E., Degens, N., IJsselsteijn, W. & Barendregt, W. (2023). Design experiments in game-based learning of metacognition. *Proceedings of the 17th European Conference on Games Based Learning*, 17*(1)*, 86-93.

Braad., E., Degens, N., Barendregt, W., & IJsselsteijn, W. (2022). Improving metacognition through self-explication in a digital self-regulated learning tool. *Educational Technology Research & Development*, 70, 2063-2090.

Braad, E. (2022). Playful metacognitive tools. Presentation held at the *Educational Innovators & Pioneers Conference (EPIC)*. May 30th to June 1st, 2022, Rotterdam, The Netherlands.

Braad., E., Degens, N., Barendregt, W., & IJsselsteijn, W. (2021). Development of a design framework for metacognition in game-based learning. *Journal of Interactive Learning Research*, *32*(4), 295-323.

Braad, E., Degens, N., & IJsselsteijn, W.A. (2020). Designing for metacognition in game-based learning: A qualitative review. *Translational Issues in Psychological Science*, *6*(1), 53–69.

Braad, E., Degens, N., & IJsselsteijn, W. A. (2019). Towards a framework for metacognition in game-based learning. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th European Conference on Games Based Learning* (pp. 101–109). Sonning Common, United Kingdom: Academic Conferences and Publishing International.

Braad, E., Degens, N., & IJsselsteijn, W. A. (2019). MeCo: A digital card game to enhance metacognitive awareness. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th European Conference on Games Based Learning* (pp. 92–100). Sonning Common, United Kingdom: Academic Conferences and Publishing International.

Braad, E. (2018). Learn-to-learn: Game-based learning for metacognition. Paper presented at the *Doctoral Consortium of the Foundations of Digital Games (FDG) Conference*. August 7-10, 2018, Malmö, Sweden.

About the Author

Eelco Braad (Smallingerland, 1981) completed his master in computing science at the University of Groningen, specializing in Computational Science & Scientific Visualization. Two papers on solving polynomial equations using combinatorial optimization were published from his graduation work. During his studies, he co-founded a game development studio and worked on various entertainment and serious game projects.

Unsatisfied with contemporary game education, he made a switch to Hanze University of Applied Science and commenced a long but steady road towards building a four-year international bachelor-level program in game design and game development. From the various cooperations with students, local companies, and researchers, two papers on design research and serious game design were published. This rekindled his interest in research, and he began as a part-time PhD-candidate.

In the present work, three main themes of his work come together: learning, playing, and technology.

Eelco is currently working as a senior researcher at Hanze University of Applied Sciences, Groningen. His research focuses on the design and implementation of digital technology to improve the effectiveness, efficiency, and enjoyability of learning. Key areas of interest include self-regulated learning, game-based learning, and design research.

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For another part, it was all about the process. This work was a parttime effort within my employment and always sat next to other roles, such as that of senior lecturer coordinating an international bachelor program, that of project leader of curriculum developments, and that of a senior researcher coordinating a line of research. Learning how to organize your work while attempting to remain effective as well as affective has been a major lesson.

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Thank you to my friends, Maarten, Janneke, Harko, Katherina, Ilja, Dineke, for creating the time and space to relax, enjoy food, music, and friendship. While these moments in our busy lives are often few and far between, whenever we are together it feels like we can pick up from the day before. Nevertheless, I wish to find more of those moments from now on.

Finally, I have to award the greatest amount of gratitude to my own family. Sometimes my energy and attention were not as available as they should be. Thank you Elske, for inviting me into your young life as your father. Thank you Amelia, for gifting your mother and I paper lips so we could kiss. Thank you Jelmer, for breaking most moments of concentrated thought with your jokes, laughter, and your smiling face pressed to mine. Thank you Joris, for completing this family and surprising us that our happiness could be multiplied still.

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Appendices

Table of Contents

Appendix A

List of reviewed studies

The following studies were included in the qualitative literature review presented in Chapter 3.

Table A.1: studies included in the qualitative literature review.

#	Publication and study
1	Bessarabova et al., (2016) – experiment 1
2	Bessarabova et al., (2016) – experiment 2
3	Bessarabova et al., (2016) – experiment 3
4	Castronovo, Van Meter, & Messner (2018)
5	Charles, Hanna, Paul, & Charles (2012)
6	Chen & Lee (2018)
7	Fessl, Bratic, & Pammer (2014)
8	Fiorella & Mayer (Fiorella & Mayer, 2012) – experiment 1
9	Fiorella & Mayer (Fiorella & Mayer, 2012) – experiment 2
10	Foster, Esper, & Griswold (2013)
11	Gallagher & Prestwich(2013)
12	Johnson (2019)
13	Ke (2008a)
14	Ke (2008c)
15	Kim, Park, & Baek (2009)
16	Sun-Lin & Chiou (2017)
17	McCarthy, Jacovina, Snow, Guerrero, & McNamara (2017)
18	Moser, Zumbach, & Deibl (2017)
19	Raybourn (Raybourn, 2009)
20	Scoresby & Shelton (2014)
21	Snow et al. (2015)
22	Sung, Hwang, Lin, & Hong (2017)
23	Tang, Shetty, & Chen (2012)
24	Tang, Shetty, Bielefeldt, et al. (2012)
25	Tüysuz (2009)
26	Usart, Romero, & Almirall (2011)
27	Verpoorten, Castaigne, Westera, & Specht (2014)

Appendix B

Game Descriptions

For the formative evaluation of the design framework, three game descriptions were constructed from three studies on metacognition in game-based learning (i.e., Kim, Park, & Baek (2009), Verpoorten, Castaigne, Westera, & Specht (2014), and Fiorella & Mayer (2012)). The scenarios can be summarized as (1) direct instruction of metacognitive strategy before playing a multiplayer fantasy game aimed at instilling economic concepts; (2) metacognitive explication prompts and metacognitive feedback on confidence within an adventure game aimed at understanding mechanics in physics; and (3) metacognitive attention prompts and scaffolding paper worksheets to be used with an electrical circuit simulation game.

Scenario 1

The goal in this scenario is to teach students economic concepts through playing a commercial massive multiplayer online role-playing game (MMORPG). The game is set in the economic context of the Choseon Dynasty of about 200 years ago. Players receive a variety of quests from Non-Player Characters (NPCs) and have to solve these quests to become a wealthy merchant.

The game has two separate sub-scenarios. In the economic scenario, the game allows the players to experience economic activities such as inflation, deflation, currency exchange, investment, international trade, and factory management for goods production. In the battle scenario, the game allows players to battle against others for better weapon items and an upgraded player level.

Figure B.1: screenshot of the MMORPG.

Before playing the game, players were trained in three metacognitive strategies (self-recording, modeling, and thinking aloud) and instructed on how to use these strategies while playing educational games. After playing, players were asked to report how often they used each strategy.

Scenario 2

The goal in this scenario is to increase the awareness and accuracy of students' confidence in the correctness of their answers. A 3D interactive adventure game is designed for this goal. The game is set in the early 17th century and casts the player in the role of an apprentice to astronomer Galileo Galilei (1564-1642).

Through performing experiments and predicting the outcomes correctly, the player aims to gain the trust of his master. In each experiment the player sets the controls of an apparatus to launch balls of different materials and predicts the trajectory the ball will follow. Additionally, the player sets a confidence slider to indicate the confidence they have in the correctness of their answer.

After executing the experiment, players receive two types of feedback: on the correctness of their prediction (i.e., regarding physics) and on the accuracy of their confidence (i.e., regarding metacognition). The trust of the master is then updated accordingly before a new experiment begins. The total trust gained reflects the player's own development of accurate confidence development.

Figure B.2: screenshot of the adventure game.

Scenario 3

The goal in this scenario is to reflect on the relevant features of a game to learn about electrical circuits. The Circuit Game consists of 10 levels in which the player is given a problem situation involving electrical circuits and must click on a choice, drag-and-drop a component into an existing circuit to accomplish some goal, or type a number into a box.

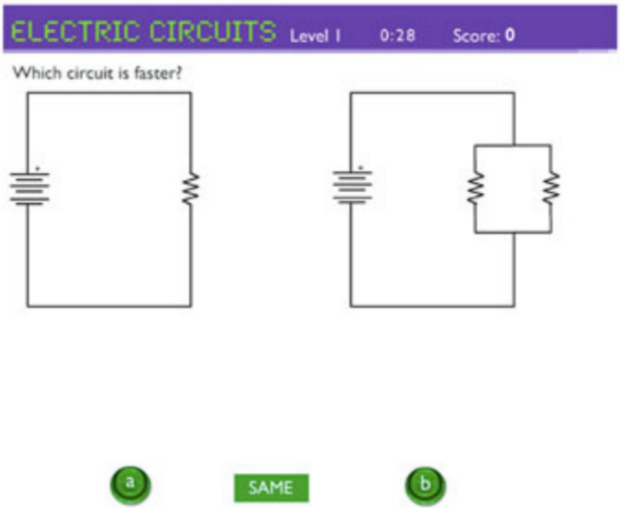

Figure B.3: screenshot of the circuit game.

The levels are focused on improving the player's knowledge of how the arrangement of batteries and resistors in a circuit affects a circuit's rate of flow.

The game is rule based, allows players to perform actions and experience what happens in response, allows players to compete with each other or with themselves, and ensures that player’s previous actions are reflected in the current state of the game, such as in the scoreboard and the level of the game.

Metacognitive prompts, printed on paper sheets, were added to the game to encourage students to focus on essential components of electrical circuits and how each of those components impacts the circuit’s rate of flow. In other words, students were prompted to relate their game activity to underlying principles associated with the content of the game.

Appendix C

Design Framework Dimensions

The final dimensions of the DFM-GBL design framework, after adjustments, are provided in Table C.1 and Table C.2 below.

Table C.1: Dimensions for Metacognitive Instruction

(1) To what extent is metacognitive instruction domain-general or domain-specific?		
Opposites	**domain-general**	**domain-specific**
Definition	metacognitive instruction makes no assumptions about or references to the learning content	metacognitive instruction is formulated in terms of the domain-specific learning content
Rationale	makes it easier for learners to apply metacognition across a wide range of learning situations	makes it easier for learners to connect metacognition to ongoing learning
References	Derry & Murphy (1986), Hannafin et al. (1992), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	

(2) To what extent is metacognitive instruction embedded within or detached from domain-specific content?		
Opposites	**embedded**	**detached**
Definition	metacognitive instruction is part of the domain-specific learning content	metacognitive instruction is separated from domain-specific learning content
Rationale	makes it easier for learners to connect metacognitive knowledge and skills to concrete and ongoing learning	makes it easier for learners to isolate and transfer aspects of metacognition to different learning situations
References	Derry & Murphy (1986), Hannafin et al. (1992), Hartman (2001a), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	

(3) To what extent is metacognitive instruction explicit or implicit about what a learner needs to do?		
Opposites	**explicit**	**implicit**
Definition	metacognitive instruction is explicit about metacognition and aimed at increasing awareness and use of metacognition	metacognitive instruction is implicit about metacognition and aimed at improving use and effectiveness of metacognition
Rationale	helps learners to increase knowledge and awareness of metacognition addresses an availability deficiency by increasing knowledge may be best suitable for novice and young learners	helps learners to produce metacognitive behaviors more often and more effectively addresses a production deficiency by improving and practicing application may be best suitable for older and more advanced learners
References	Bannert & Mengelkamp (2013), Derry & Murphy (1986), Osman & Hannafin (1992), Ke (2016), Lin (2001), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	

(4) To what extent is metacognitive instruction controlled by the system or by the learner?		
Opposites	system-controlled	learner-controlled
Definition	metacognitive instruction provides a learner with clear directions on what to do next	metacognitive instruction is available upon request from the learner
Rationale	makes learners perform effective metacognitive activities through guided practice may be used in the short term if gradually faded over time	the ultimate goal is to become independent of external guidance allows learners to practice self-guidance without restriction
References	Azevedo et al. (2012), Bannert & Mengelkamp (2013), Derry & Murphy (1986), Graesser (2017), Osman & Hannafin (1992), Hartman (2001b), Lin (2001), Mayer (2016), Nietfeld & Shores (2011), Roll, Aleven, McLaren, & Koedinger (2007).	

(5) To what extent is metacognitive instruction intrinsically integrated with the gameplay activities?		
Opposites	**extrinsically integrated**	**intrinsically integrated**
Definition	metacognitive instruction is situated outside of the gameplay activities	metacognitive instruction is situated within the gameplay activities
Rationale	reduces cognitive load and increases relevance of feedback to playing, learning, and metacognition	performance and motivation are positively impacted by meshing learning content with play
	may disrupt flow and be perceived as irrelevant	is unclear if this principle extends to integration of metacognitive instruction with gameplay
	may be unavoidable for complex learning content or content reflective in nature	
References	Graesser (2017), Habgood & Ainsworth (2011), Ke (2016), Nietfeld & Shores (2011), Plass et al. (2015).	

Table C.2: Dimensions for Gameplay

(1) To what extent does the game involve social or individual interactions?		
Opposites	**individual**	**social**
Definition	a single player interacting with a GBLE	a range of players interacting within or outside of a GBLE
Rationale	allows learners to apply metacognition in their own way and at their own tempo	playing in groups is one of three most salient factors in effective GBL
	lack of social comparison promotes learners to experiment and risk failure	metacognition can be facilitated through social interactions within GBL
	individual debriefing of GBL is more effective than group-based debriefing	
References	Kim et al. (2009), Usart, Romero & Almirall (2011), Van Der Meij, Leemkuil, & Li (2013), Wouter & Van Oostendorp (2013).	
(2) To what extent does the game involve competition or collaboration between agents?		
Opposites	**competitive**	**collaborative**
Definition	artificial conflict between agents	agents working together towards their goals
Rationale	produces motivation through challenge	collaboration in games can improve metacognition
	allows performance comparisons	collaboration fosters modelling metacognitive strategies from others
		collaboration fosters explication of otherwise covert metacognition
References	Ke (2008b, 2008a), Kim et al. (2009), Nietfeld & Shores (2011), Sanchez (2017), Schraw, Crippen, & Hartley (2006), Ter Vrugte et al. (2015), Usart et al. (2011), Vlachopoulos & Makri (2017), Zheng, Li, Zhang, & Sun (2019).	
(3) To what extent does the game involve deliberate or reactive responses from the player?		
Opposites	**deliberate**	**reactive**
Definition	players can deliberately consider and effectuate a choice	player must react quickly to changes in the game
Rationale	articulates thinking and allows learners to relate in-game choices to underlying principles	integrating learning content with action-based gameplay could hamper learning
References	Habgood & Ainsworth (2011), Martinez-Garza & Clark (2017), Mayer (2016).	

(4) To what extent is the game fidelitous to or fictitious about representing the target learning situation?		
Opposites	**fidelitous**	**fictitious**
Definition	the game environment looks, feels, smells, tastes, and/or altogether appears and responds similar to the real world	the game environment deviates from representing and simulating reality
Rationale	strengthens the link between in-game and real-world concepts and situations, thereby improving transfer of learning	can emphasize relevant learning content by offering a more effective representation
		can improve motivation through fantasy and curiosity
		shifting rules can trigger metacognitive processing
References	Gallagher & Prestwich (2013, Ke (2016), Mayer (2016), Rooney (2012).	

Appendix D

Design Dimensions for ML-2

Chapter 5 discusses an experiment with a digital tool that supports metacognitive development during self-regulated learning. However, this tool does not implement any gameplay elements. For the sake of brevity, and to allow the chapter to be read on its own, the tool is not described in terms of the DFM-GBL framework within the chapter. Alternatively, such a description and accompanying dashboard visualization are provided here. Naturally, the gameplay components are omitted for both.

Table D.1: Design rationale of ML-2 in terms of the DFM-GBL.

Design Dimensions for Instruction
(1) domain-general/domain-specific: Metacognitive training is *domain-general* to allow the tool to be used regardless of learning content. This in turn allows increased opportunities for learners to practice and develop metacognition. The approach of goal-setting, strategic planning, and controlling and evaluating strategy applies to a wide range of learning contexts.
(2) embedded/detached: Metacognitive training is *detached from* domain-specific training to allow the tool to be used regardless of learning content.
(3) explicit/implicit: Metacognitive training is *explicit* as the learner is provided with instructions to set goals, plan activities, select strategies, and reflect upon the outcomes thereof.
(4) system-controlled/learner-controlled: The *learner controls* how and when to use the available features, while the *system controls* which features are available and how user input is handled. The learner does control the content of the GBLE in terms of the goals they set and plans they make.

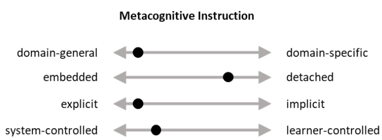

Figure D.1: design dimension dashboard visualization for ML-2.

Appendix E

Design Principles within the Design Framework

Overview of the design principles within the DFM-GBL dimensions and corresponding literature on metacognitive training (in general), game-based learning (in general), and game-based metacognitive training (in specific).

Table E.1: design principles for instruction.

Design Dimensions for Instruction		**Background**		
design principle	*definition*	*metacognitive training (in general)*	*game-based learning (in general)*	*game-based metacognitive training (in specific)*
(1) To what extent is metacognitive instruction domain-general or domain-specific?				
domain-general training principle	domain-general training can be applied to a wide range of domains and learning content and thus offers learners more frequent and more diverse opportunities to practice metacognition	(Derry & Murphy, 1986; Osman & Hannafin, 1992; Schraw, 1998)		(Fiorella & Vogel-Walcutt, 2011)
domain-general transfer support principle	domain-general training must help learners to make the connection to domain-specific and ongoing learning by identify transferrable	(Derry & Murphy, 1986; Osman &		(Braad et al., 2019b)

	metacognitive knowledge and skills and promoting this transfer	Hannafin, 1992; Schraw, 1998)		
(2) To what extent is metacognitive instruction embedded within or detached from domain-specific content?				
embedding principle	embedding metacognitive training in domain-specific learning content makes it easier for learners to make the connection	(Bannert & Mengelkamp, 2013; Veenman et al., 2006)		
(3) To what extent is the metacognitive instruction explicit or implicit about what a learner needs to do?				
explicit information principle	informing learners beforehand of the goals and benefits of metacognitive training emphasizes its usefulness and motivates learners to invest the required effort	(Bannert & Mengelkamp, 2013; Lin, 2001; Veenman et al., 2006)		
self-explanation principle	stimulating learners to self-explain their problem-solving process and ways of thinking helps them to develop and improve metacognition	(Bannert & Mengelkamp, 2013; Lin, 2001; Osman & Hannafin, 1992; Veenman et al., 2006)	(Ter Vrugte & De Jong, 2017)	(Castronovo et al., 2018; Fiorella & Mayer, 2012; Mayer, 2016; Nietfeld & Shores, 2011)
self-explication principle	stimulating learners to make explicit their assumptions about learning and choices during their learning process helps them to develop and improve metacognition			Chapter 3: Qualitative Review Chapter 4: Improving Metacognition with a Digital Tool
metacognitive feedback principle	providing learners with feedback on their metacognitive activities helps them to develop and improve metacognition	(H. W. Lee, Lim, & Grabowski, 2010; Roll et al., 2006)		(Snow, McNamara, et al., 2015; Verpoorten et al., 2014) Chapter 3: Qualitative Review

(4) To what extent is metacognitive instruction controlled by the system or by the learner?				
extended practice and assessment principle	providing learners with enough time, prolonged training, and frequent opportunities to assess comprehension is required for learners to develop and automate metacognition	(Azevedo et al., 2012; Bannert & Mengelkamp, 2013; Lin, 2001; Osman & Hannafin, 1992; Veenman et al., 2006)		
learning cycle principle	supporting all three SRL-phases of planning, performance, and evaluation is required for learners allows learners to apply evaluation outcomes to subsequent phases and helps them to develop and improve metacognition	(Zimmerman & Tsikalas, 2005)		(Nietfeld & Shores, 2011)
(5) To what extent is metacognitive instruction intrinsically integrated with the gameplay activities?				
intrinsic integration principle	integrating learning goals and activities with gameplay goals and activities ensures that engaging with the gameplay becomes equivalent with engaging in learning		(Arnab et al., 2015; Carvalho et al., 2015; Habgood, 2007; Habgood & Ainsworth, 2011; Ke, 2016) Chapter 1: Introduction	(Verpoorten et al., 2014)
alignment principle	aligning game activities and goals with learning activities and goals ensures that engagement resulting from gameplay is directed at initiating and sustaining learning		(Amory, 2007; Arnab et al., 2012, 2015; Bedwell et al., 2012; Carvalho et al., 2015; Hung & Van Eck, 2010; Lim et al., 2013)	

		Chapter 1: Introduction
alternating activities principle	combining playing with learning by alternating playing activities and learning activities ensures both types of activities are performed but risks not sufficiently engaging learners to continue playing or learning	(Rieber, 1996; Squire, 2006) Chapter 1: Introduction

Table E.2: design dimensions for gameplay.

Design Dimensions for Gameplay		**Background**		
design principle	*definition*	*metacognitive training (in general)*	*game-based learning (in general)*	*game-based metacognitive training (in specific)*
(1) To what extent does the game involve social or individual interactions?				
individual practice principle	as metacognitive development differs between individuals, learners benefit from individual and personalized training	(Veenman et al., 2006)		(Mayer, 2016)
social incentive principle	social incentives are generally effective at engaging learners with gameplay as well as learning content	(Ryan & Deci, 2000) [4]	(Barab, Dodge, Tuzun, Job-Sluder, et al., 2007; Steinkuehler & Tsaasan, 2019; Ter Vrugte et al., 2015)	
social identification principle	social identification, or modeling one's behavior after that of another learner, is an effective mechanism to promote metacognition;	(Hartman, 2001b)	(Malone, 1981)	(Kim et al., 2009; White & Frederiksen, 1998)
social reinforcement principle	social reinforcement, or the increased likelihood of engage in in behavior as observed in other learners, is an effective mechanism to encourage learners to engage in activities	(Bandura, 1977, 1986)[4] (Zimmerman, 1990)	(Malone, 1981)	

[4] These references are shown in the column on metacognitive training in general, but refer to learning in general and not necessarily pertain to metacognition.

(2) To what extent does the game involve competition or collaboration between agents?				
collaboration principle	using collaboration between peer learners and/or supervisors and using the affordances of GBL for adding collaboration with virtual companions are effective ways to help learners to develop and improve metacognition			(Nietfeld & Shores, 2011; Usart et al., 2011; White & Frederiksen, 2005, 1998)
competition principle	competition with other players is an effective mechanism to promote motivation through social incentive and as an additional challenge;	(Burguillo, 2010)[4]	(Malone & Lepper, 1987; Romero et al., 2012; Sanchez, 2017; Ter Vrugte et al., 2015)	
collaboration/competition principle	a combination of intragroup collaboration and intergroup competition is an effective mechanism to encourage learners to initiate and sustain gameplay activities		(Plass et al., 2015; Sanchez, 2017)	(Ke, 2008b, 2008c)
(3) To what extent does the game involve deliberate or reactive responses from the player?				
game mechanics motivation and learning principle	the challenges and objectives, actions and responses, and feedback can pertain to gaming, to learning		(Arnab et al., 2015; Carvalho et al., 2015; Ke, 2016; Malone & Lepper, 1987)	
game flow principle	through playing a game, the player will become better at the playing the game and to maintain sufficient challenge (while avoiding boredom and anxiety), gameplay must increase in difficulty as the player progresses (theory of flow)		(Hamari et al., 2016; Paras & Bizzocchi, 2005; Schell, 2019)	
challenge motivation and learning principle	challenge provided by the system affects learning through increased engagement as well as directly		(Hamari et al., 2016; Malone & Lepper, 1987)	(Sun-Lin & Chiou, 2017)

cognitive load principle	complex gameplay involving choices with many possibilities must be avoided to avoid cognitive overload of the learner	(Veenman et al., 2006)	(Azevedo et al., 2012; Kalyuga & Plass, 2009)	
(4) To what extent is the game fidelitous to or fictitious about representing the target learning situation?				
narrative motivation and learning principle	the narrative setting and plot can provide motivation through curiosity as to what has happened or will or could happen next, while at the same time using metaphor and analogy to provide a cognitive framework supporting learning		(Barab et al., 2005; Dickey, 2019; Malone & Lepper, 1987; Van Oostendorp & Wouters, 2017)	
realism principle	metacognitive training, and in particular pedagogical agents, in games need not be perceptually realistic to be effective			(Mayer, 2016)

Appendix F

Learning strategies

Overview of the learning strategies implemented in GBLEs in Design Experiments #2 and #3 as discussed in Chapter 6.

Table F.1: learning strategies implemented in Design Experiment #2 and #3.

Strategy	Description	DE#2	DE#3
Skim	Looking over a text to get a general overview of the material	V	
Highlighting	Reading through a text while marking the important information	V	
Rehearsing	Practice the learning materials, e.g., repeatedly writing down a formula to help you remember	V	
Practice testing	Test how many of the learning materials you actually know by making assignments or taking a practice exam	V	
Keyword mnemonics	Making a rhyme, song or an acronym out of the information to make it easier to remember	V	
Summarizing	Writing a summary of the learning materials	V	
Elaborative interrogation	Question yourself on why an explicitly stated fact or concept is true	V	
Self-testing	Ask yourself questions about the learning materials and try to answer them without looking at the answers	V	
Self-consequentiating	Think of ways in which you can reward or punish yourself for success or failure during the learning process	V	V
Self-evaluating	Going over your work to check the quality	V	V
Seeking information	Gathering information pertinent to the topic you study	V	V
Seeking social assistance	Asking another person for help, either online or in real life	V	V

Keeping records	Taking notes while writing or reading sources	V	V
Reviewing records	Rereading notes or the txt you have produced so far	V	V
Outlining	Making an outline of the main points, as preparation for writing a paper or detailed reading of a text	V	V
Imagery	Draw a picture, diagram, or flowchart to visualize the information that you want to understand or transfer	V	V
Environmental structuring	Finding a quiet place to work by isolating yourself from anything that may be distracting	V	V
Organizing	Ordering your notes or your source materials		V
Revising	Modifying your text or plans for writing		V
Self-monitoring	Checking to see if your writing goals are met, to verify whether you are on track		V
Self-verbalizing	Saying dialogue out loud while writing or articulating what needs to be done		V
Self-selecting models	Emulating the tactics or style of writing of a more gifted author		V

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