chapter six

Improving Metacognition with Game-Based Learning

This chapter is part of Braad, E. (2024). *Designing Game-Based Learning for Training Metacognition* [Doctoral dissertation, Eindhoven University of Technology].

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.

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.

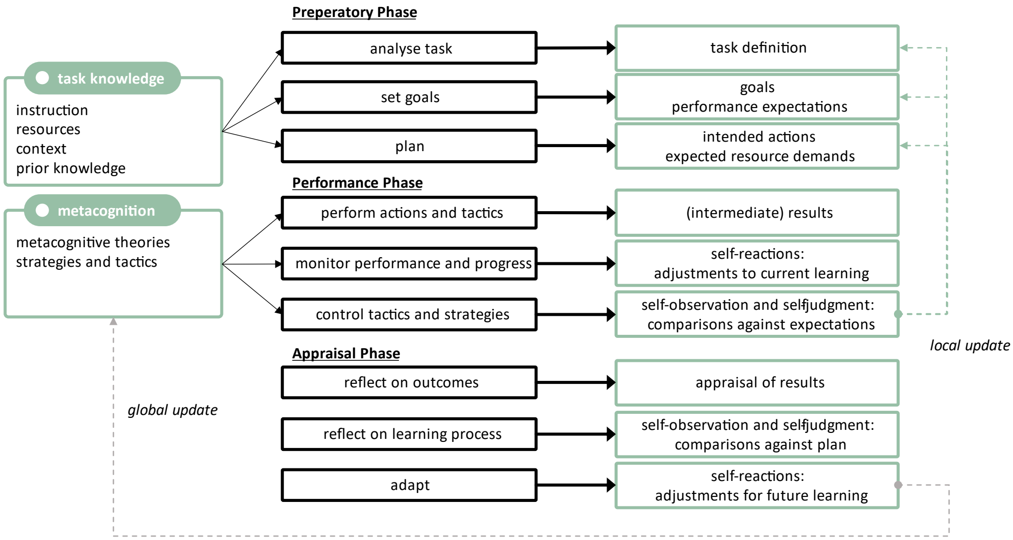


Figure 5.2: Conceptual model of metacognition during self-regulated learning.

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).

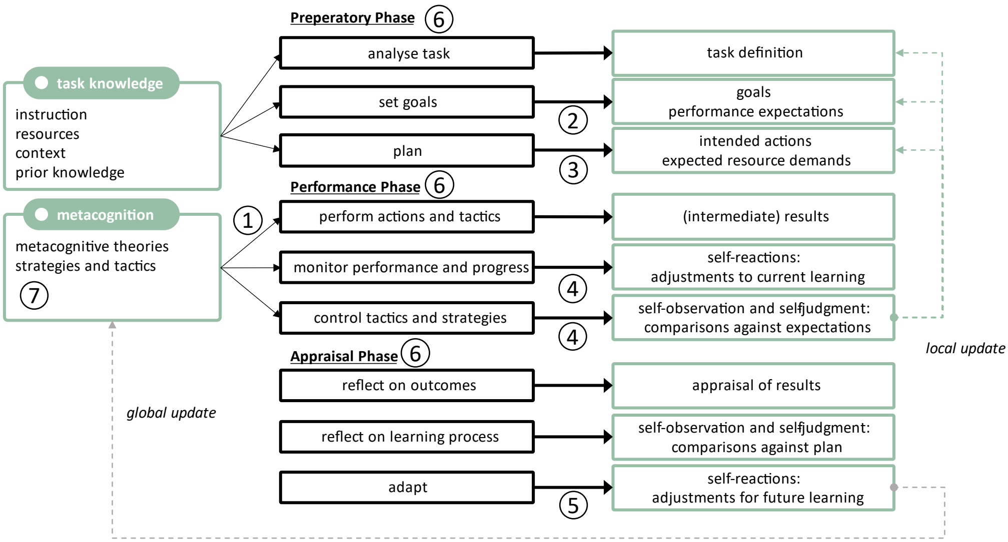


Figure 5.3: Metacognitive mechanisms indicated in the conceptual model.

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.

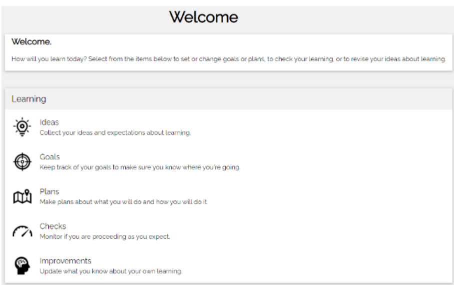


Figure 5.4: Main menu of the tool with the five categories of learning.

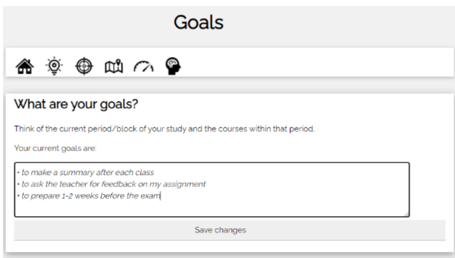


Figure 5.5: Category screen with the main prompt for the goals category.

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.

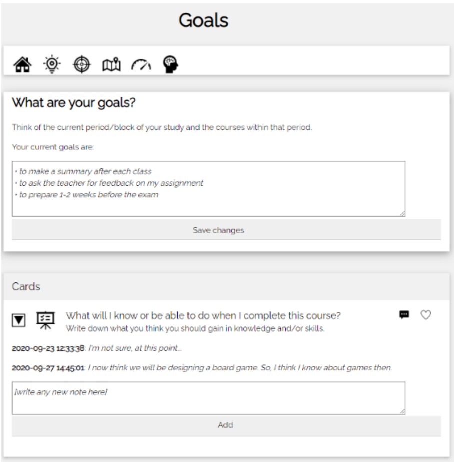


Figure 5.6: Unlocked cards with refined prompts below the main prompt.

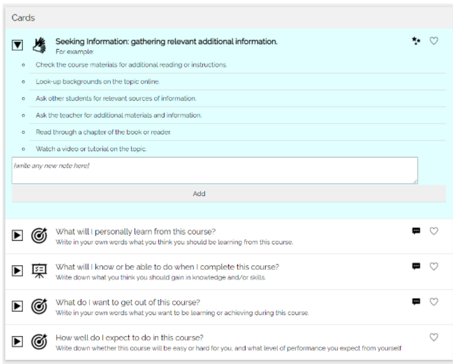


Figure 5.7: An unlocked card highlighting a metacognitive strategy.

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) - need for cognition - metacognitive awareness - self-efficacy - expected performance	*Intervention Groups:* - metacognitive activities - frequency of use - duration of use *Comparison Group:* - none	- metacognitive awareness - self-efficacy - expected performance - 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.

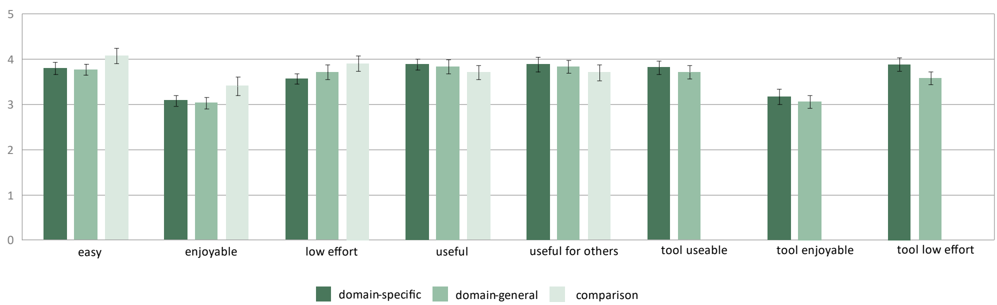


Figure 5.8: Quantitative results of the evaluation questionnaire.

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." "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."	+11.3%	+27.5%
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." "I have started to think better about how I can best deal with my studying materials."	+3.7%	+9.9%
Helped me to be more retrospective, helped me evaluate and reflect upon what I do.	"It made me more retrospective of my learning." "It helped me evaluate my learning skills and find methods and ways to improve on them."	+12.2%	+26.1%
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." "I realized that writing down daily tasks and future goals improves my productivity immensely."	-1.6%	-9.8%
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.

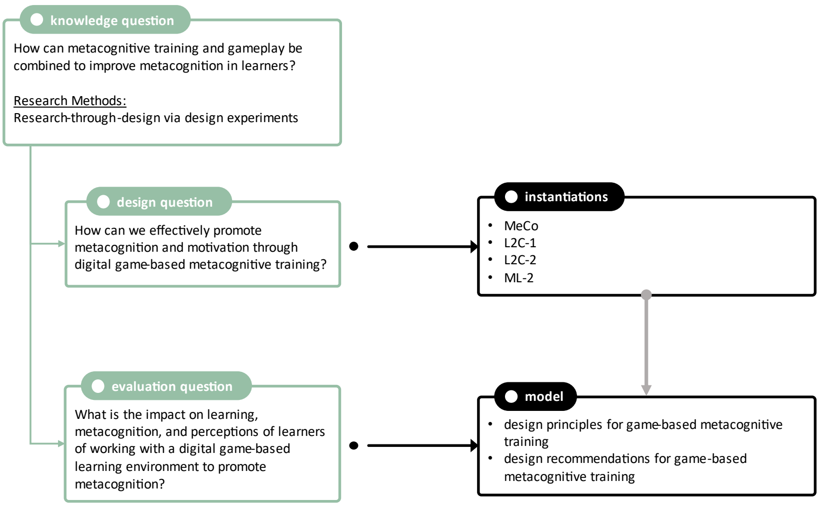


Figure 6.1: research flow for Chapter 6.

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.

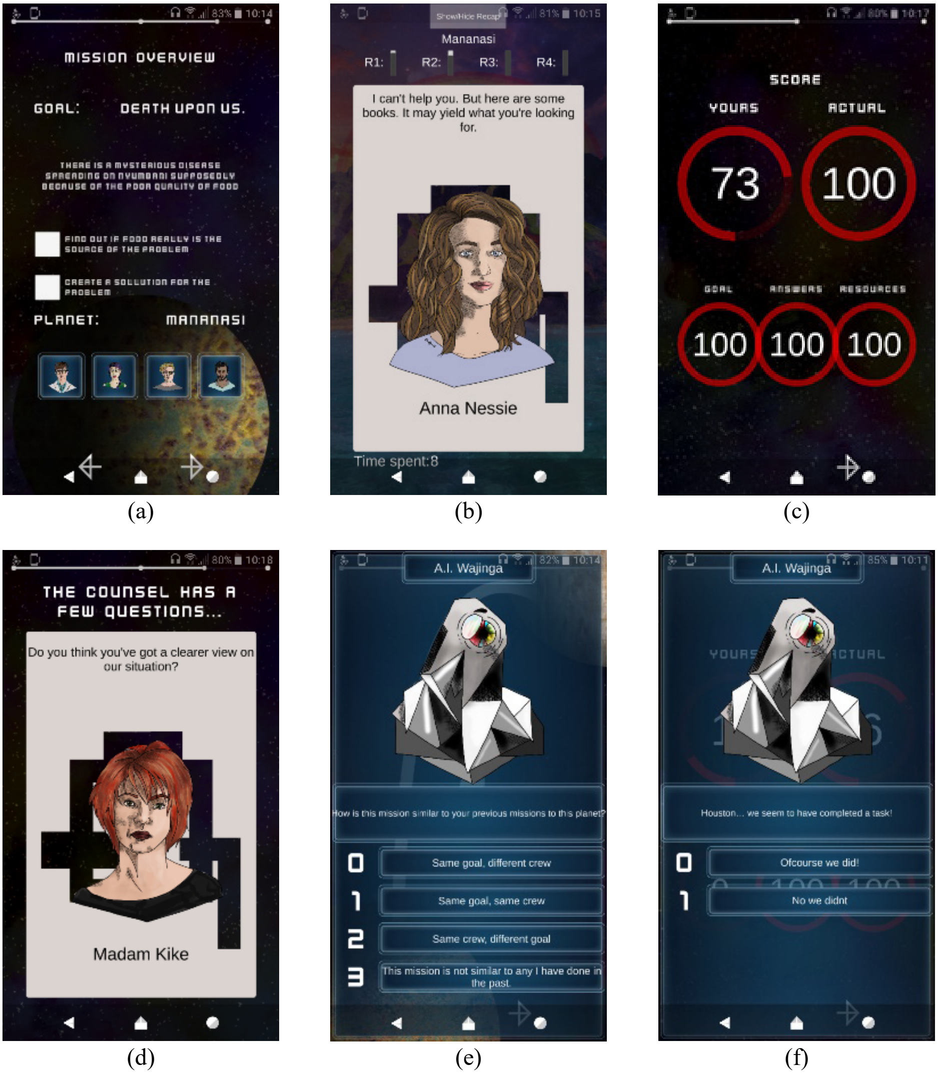


Figure 6.2: An overview of different screens in MeCo: (a) mission overview, (b) metacognitive question during planning, (c) crew member suggestion during performance, (d) senior council member during revaluation, (e) comparison of estimated and actual mission success, and (f) metacognitive question during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

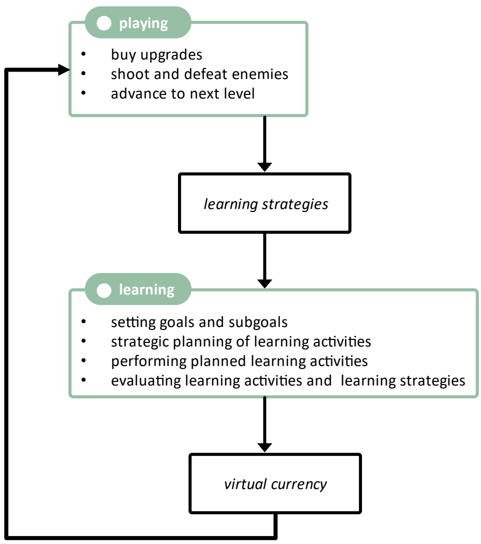
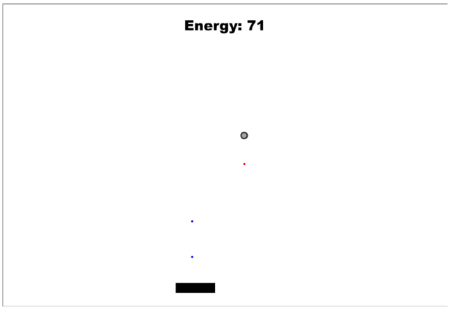


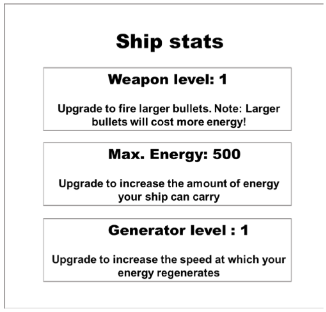
Figure 6.3: Playing and learning loop in L2C-1.

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.

<u>Metacognition</u>

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).

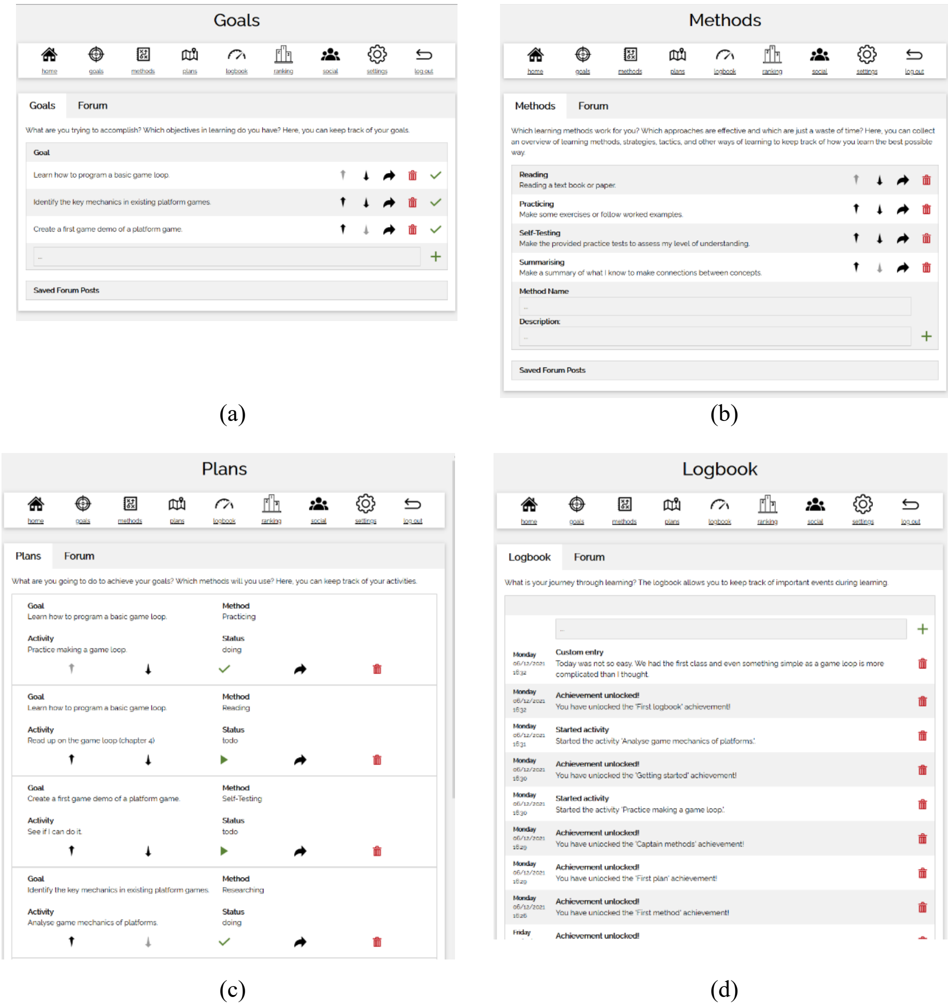


Figure 6.5: Screens for the SRL features of goals, methods, plans, and the logbook.

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).

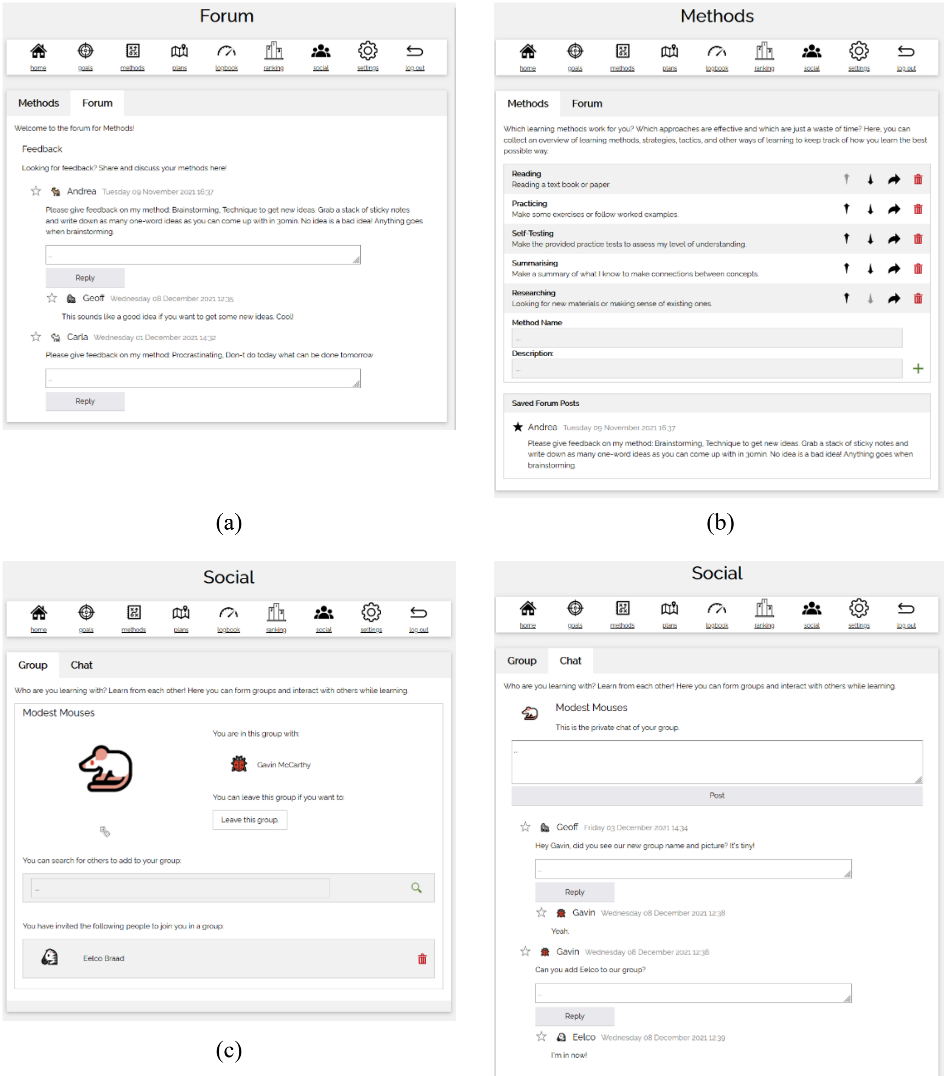


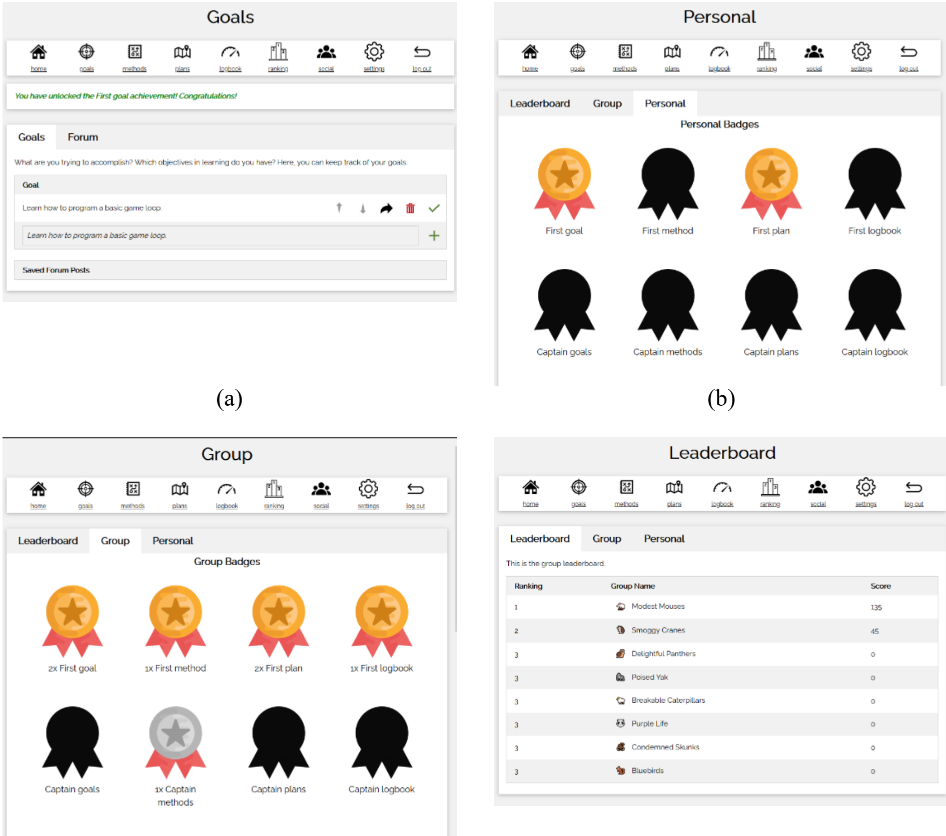
Figure 6.6: Screens for the social features of forums, saving a forum post to show on the category main page, forming a group, and a private group chat.

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.



(a) (b)

(c) (d)

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	The GBLE supports various types of social interaction, both to improve metacognition directly and to motivate learners.
social identification principle *social reinforcement principle*	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.

<u>Participants</u>

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.

<u>Measures</u>

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.

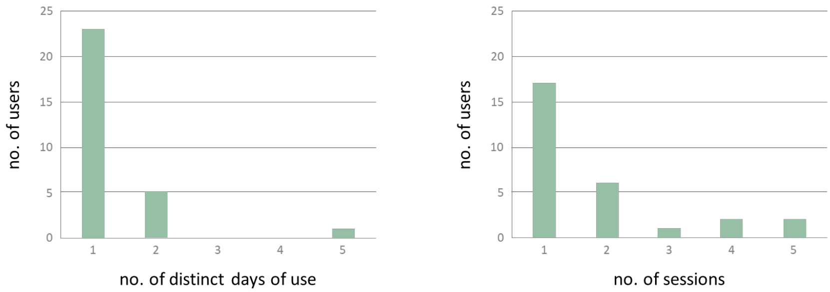
From the post-test responses, $N = 18$ participants within the intervention group completed the questions regarding evaluation of the tool, of which $N = 9$ did and another $N = 9$ did not use the GBLE.

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*").

Usage

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).



(a) (b)

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, $t(86) = -.873$, $p = .385$.

<u>Metacognition</u>

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.

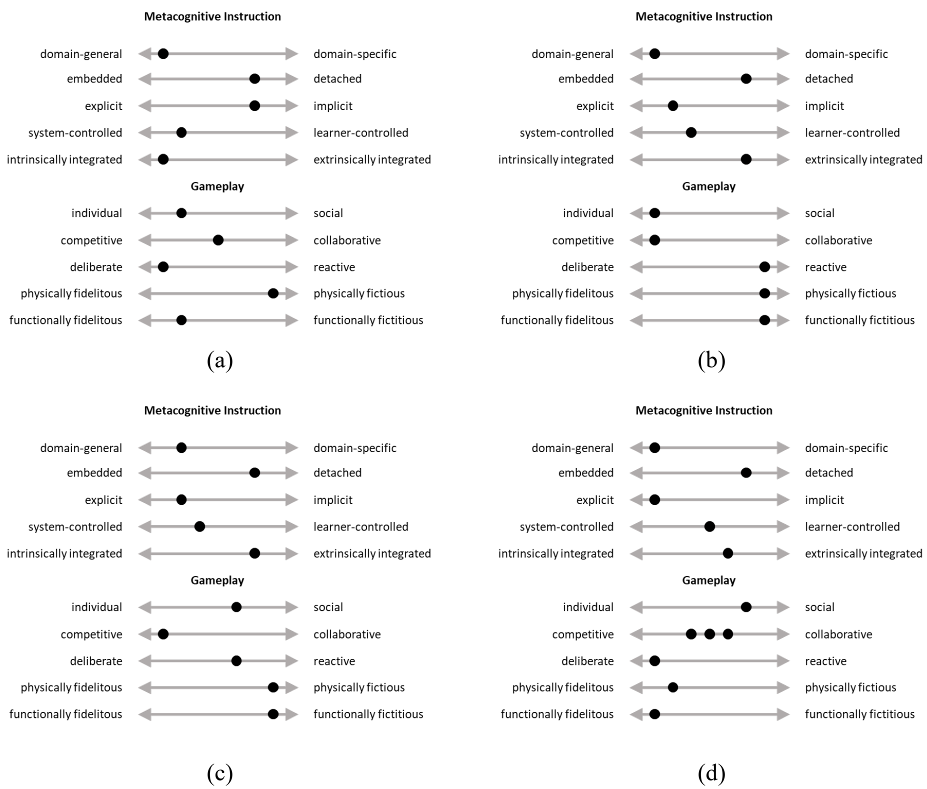


Figure 6.9: Overview of design dimension dashboard visualizations, one for each design experiment: (a) MeCO, (b) L2C-1, (c) L2C-2, and (d) ML-2.

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.

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