
Appendices

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Appendix A

List of reviewed studies

The following studies were included in the qualitative literature review presented in Chapter 3.

Table A.1: studies included in the qualitative literature review.

#	Publication and study
1	Bessarabova et al., (2016) – experiment 1
2	Bessarabova et al., (2016) – experiment 2
3	Bessarabova et al., (2016) – experiment 3
4	Castronovo, Van Meter, & Messner (2018)
5	Charles, Hanna, Paul, & Charles (2012)
6	Chen & Lee (2018)
7	Fessler, Bratic, & Pammer (2014)
8	Fiorella & Mayer (Fiorella & Mayer, 2012) – experiment 1
9	Fiorella & Mayer (Fiorella & Mayer, 2012) – experiment 2
10	Foster, Esper, & Griswold (2013)
11	Gallagher & Prestwich(2013)
12	Johnson (2019)
13	Ke (2008a)
14	Ke (2008c)
15	Kim, Park, & Baek (2009)
16	Sun-Lin & Chiou (2017)
17	McCarthy, Jacovina, Snow, Guerrero, & McNamara (2017)
18	Moser, Zumbach, & Deibl (2017)
19	Raybourn (Raybourn, 2009)
20	Scoresby & Shelton (2014)
21	Snow et al. (2015)
22	Sung, Hwang, Lin, & Hong (2017)
23	Tang, Shetty, & Chen (2012)
24	Tang, Shetty, Bielefeldt, et al. (2012)
25	Tüysüz (2009)
26	Usart, Romero, & Almirall (2011)
27	Verpoorten, Castaigne, Westera, & Specht (2014)

Appendix B

Game Descriptions

For the formative evaluation of the design framework, three game descriptions were constructed from three studies on metacognition in game-based learning (i.e., Kim, Park, & Baek (2009), Verpoorten, Castaigne, Westera, & Specht (2014), and Fiorella & Mayer (2012)). The scenarios can be summarized as (1) direct instruction of metacognitive strategy before playing a multiplayer fantasy game aimed at instilling economic concepts; (2) metacognitive explication prompts and metacognitive feedback on confidence within an adventure game aimed at understanding mechanics in physics; and (3) metacognitive attention prompts and scaffolding paper worksheets to be used with an electrical circuit simulation game.

Scenario 1

The goal in this scenario is to teach students economic concepts through playing a commercial massive multiplayer online role-playing game (MMORPG). The game is set in the economic context of the Choseon Dynasty of about 200 years ago. Players receive a variety of quests from Non-Player Characters (NPCs) and have to solve these quests to become a wealthy merchant.

The game has two separate sub-scenarios. In the economic scenario, the game allows the players to experience economic activities such as inflation, deflation, currency exchange, investment, international trade, and factory management for goods production. In the battle scenario, the game allows players to battle against others for better weapon items and an upgraded player level.



Figure B.1: screenshot of the MMORPG.

Before playing the game, players were trained in three metacognitive strategies (self-recording, modeling, and thinking aloud) and instructed on how to use these strategies while playing educational games. After playing, players were asked to report how often they used each strategy.

Scenario 2

The goal in this scenario is to increase the awareness and accuracy of students' confidence in the correctness of their answers. A 3D interactive adventure game is designed for this goal. The game is set in the early 17th century and casts the player in the role of an apprentice to astronomer Galileo Galilei (1564-1642).

Through performing experiments and predicting the outcomes correctly, the player aims to gain the trust of his master. In each experiment the player sets the controls of an apparatus to launch balls of different materials and predicts the trajectory the ball will follow. Additionally, the player sets a confidence slider to indicate the confidence they have in the correctness of their answer.

After executing the experiment, players receive two types of feedback: on the correctness of their prediction (i.e., regarding physics) and on the accuracy of their confidence (i.e., regarding metacognition). The trust of the master is then updated accordingly before a new experiment begins. The total trust gained reflects the player's own development of accurate confidence development.



Figure B.2: screenshot of the adventure game.

Scenario 3

The goal in this scenario is to reflect on the relevant features of a game to learn about electrical circuits. The Circuit Game consists of 10 levels in which the player is given a problem situation involving electrical circuits and must click on a choice, drag-and-drop a component into an existing circuit to accomplish some goal, or type a number into a box.

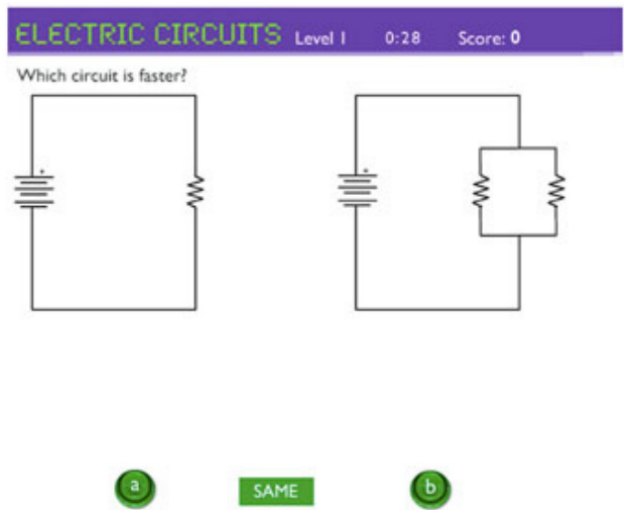


Figure B.3: screenshot of the circuit game.

The levels are focused on improving the player’s knowledge of how the arrangement of batteries and resistors in a circuit affects a circuit’s rate of flow.

The game is rule based, allows players to perform actions and experience what happens in response, allows players to compete with each other or with themselves, and ensures that player's previous actions are reflected in the current state of the game, such as in the scoreboard and the level of the game.

Metacognitive prompts, printed on paper sheets, were added to the game to encourage students to focus on essential components of electrical circuits and how each of those components impacts the circuit's rate of flow. In other words, students were prompted to relate their game activity to underlying principles associated with the content of the game.

Appendix C

Design Framework Dimensions

The final dimensions of the DFM-GBL design framework, after adjustments, are provided in Table C.1 and Table C.2 below.

Table C.1: Dimensions for Metacognitive Instruction

(1) To what extent is metacognitive instruction domain-general or domain-specific?		
Opposites	domain-general	domain-specific
Definition	metacognitive instruction makes no assumptions about or references to the learning content	metacognitive instruction is formulated in terms of the domain-specific learning content
Rationale	makes it easier for learners to apply metacognition across a wide range of learning situations	makes it easier for learners to connect metacognition to ongoing learning
References	Derry & Murphy (1986), Hannafin et al. (1992), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	
(2) To what extent is metacognitive instruction embedded within or detached from domain-specific content?		
Opposites	embedded	detached
Definition	metacognitive instruction is part of the domain-specific learning content	metacognitive instruction is separated from domain-specific learning content
Rationale	makes it easier for learners to connect metacognitive knowledge and skills to concrete and ongoing learning	makes it easier for learners to isolate and transfer aspects of metacognition to different learning situations
References	Derry & Murphy (1986), Hannafin et al. (1992), Hartman (2001a), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	

(3) To what extent is metacognitive instruction explicit or implicit about what a learner needs to do?

<i>Opposites</i>	explicit	implicit
<i>Definition</i>	metacognitive instruction is explicit about metacognition and aimed at increasing awareness and use of metacognition	metacognitive instruction is implicit about metacognition and aimed at improving use and effectiveness of metacognition
<i>Rationale</i>	helps learners to increase knowledge and awareness of metacognition addresses an availability deficiency by increasing knowledge may be best suitable for novice and young learners	helps learners to produce metacognitive behaviors more often and more effectively addresses a production deficiency by improving and practicing application may be best suitable for older and more advanced learners
<i>References</i>	Bannert & Mengelkamp (2013), Derry & Murphy (1986), Osman & Hannafin (1992), Ke (2016), Lin (2001), Pintrich (2002), Schraw (1998), Veenman et al. (2006).	

(4) To what extent is metacognitive instruction controlled by the system or by the learner?

<i>Opposites</i>	<u>system-controlled</u>	<u>learner-controlled</u>
<i>Definition</i>	metacognitive instruction provides a learner with clear directions on what to do next	metacognitive instruction is available upon request from the learner
<i>Rationale</i>	makes learners perform effective metacognitive activities through guided practice may be used in the short term if gradually faded over time	the ultimate goal is to become independent of external guidance allows learners to practice self-guidance without restriction
<i>References</i>	Azevedo et al. (2012), Bannert & Mengelkamp (2013), Derry & Murphy (1986), Graesser (2017), Osman & Hannafin (1992), Hartman (2001b), Lin (2001), Mayer (2016), Nietfeld & Shores (2011), Roll, Aleven, McLaren, & Koedinger (2007).	

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

<i>Opposites</i>	extrinsically integrated	intrinsically integrated
<i>Definition</i>	metacognitive instruction is situated outside of the gameplay activities	metacognitive instruction is situated within the gameplay activities
<i>Rationale</i>	reduces cognitive load and increases relevance of feedback to playing, learning, and metacognition may disrupt flow and be perceived as irrelevant may be unavoidable for complex learning content or content reflective in nature	performance and motivation are positively impacted by meshing learning content with play is unclear if this principle extends to integration of metacognitive instruction with gameplay
<i>References</i>	Graesser (2017), Habgood & Ainsworth (2011), Ke (2016), Nietfeld & Shores (2011), Plass et al. (2015).	

Table C.2: Dimensions for Gameplay

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

(4) To what extent is the game fidelitous to or fictitious about representing the target learning situation?

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

Appendix D

Design Dimensions for ML-2

Chapter 5 discusses an experiment with a digital tool that supports metacognitive development during self-regulated learning. However, this tool does not implement any gameplay elements. For the sake of brevity, and to allow the chapter to be read on its own, the tool is not described in terms of the DFM-GBL framework within the chapter. Alternatively, such a description and accompanying dashboard visualization are provided here. Naturally, the gameplay components are omitted for both.

Table D.1: Design rationale of ML-2 in terms of the DFM-GBL.

Design Dimensions for Instruction
(1) domain-general/domain-specific: Metacognitive training is <i>domain-general</i> to allow the tool to be used regardless of learning content. This in turn allows increased opportunities for learners to practice and develop metacognition. The approach of goal-setting, strategic planning, and controlling and evaluating strategy applies to a wide range of learning contexts.
(2) embedded/detached: Metacognitive training is <i>detached from</i> domain-specific training to allow the tool to be used regardless of learning content.
(3) explicit/implicit: Metacognitive training is <i>explicit</i> as the learner is provided with instructions to set goals, plan activities, select strategies, and reflect upon the outcomes thereof.
(4) system-controlled/learner-controlled: The <i>learner controls</i> how and when to use the available features, while the <i>system controls</i> which features are available and how user input is handled. The learner does control the content of the GBLE in terms of the goals they set and plans they make.

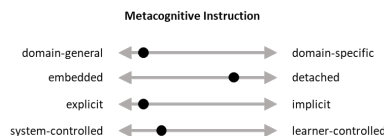


Figure D.1: design dimension dashboard visualization for ML-2.

Appendix E

Design Principles within the Design Framework

Overview of the design principles within the DFM-GBL dimensions and corresponding literature on metacognitive training (in general), game-based learning (in general), and game-based metacognitive training (in specific).

Table E.1: design principles for instruction.

Design Dimensions for Instruction		Background		
<i>design principle</i>	<i>definition</i>	<i>metacognitive training (in general)</i>	<i>game-based learning (in general)</i>	<i>game-based metacognitive training (in specific)</i>
(1) To what extent is metacognitive instruction domain-general or domain-specific?				
domain-general training principle	domain-general training can be applied to a wide range of domains and learning content and thus offers learners more frequent and more diverse opportunities to practice metacognition	(Derry & Murphy, 1986; Osman & Hannafin, 1992; Schraw, 1998)		(Fiorella & Vogel-Walcutt, 2011)
domain-general transfer support principle	domain-general training must help learners to make the connection to domain-specific and ongoing learning by identify transferrable	(Derry & Murphy, 1986; Osman &		(Braad et al., 2019b)

metacognitive knowledge and skills and
promoting this transfer

Hannafin, 1992;
Schraw, 1998)

(2) To what extent is metacognitive instruction embedded within or detached from domain-specific content?

embedding principle

embedding metacognitive training in domain-
specific learning content makes it easier for
learners to make the connection

(Bannert &
Mengelkamp, 2013;
Veenman et al., 2006)

(3) To what extent is the metacognitive instruction explicit or implicit about what a learner needs to do?

explicit information
principle

informing learners beforehand of the goals and
benefits of metacognitive training emphasizes its
usefulness and motivates learners to invest the
required effort

(Bannert &
Mengelkamp, 2013;
Lin, 2001; Veenman et
al., 2006)

self-explanation principle

stimulating learners to self-explain their problem-
solving process and ways of thinking helps them
to develop and improve metacognition

(Bannert &
Mengelkamp, 2013;
Lin, 2001; Osman &
Hannafin, 1992;
Veenman et al., 2006)

(Ter Vrugte & De
Jong, 2017)

(Castronovo et al., 2018;
Fiorella & Mayer, 2012;
Mayer, 2016; Nietfeld &
Shores, 2011)

self-explication principle

stimulating learners to make explicit their
assumptions about learning and choices during
their learning process helps them to develop and
improve metacognition

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Digital Tool

metacognitive feedback
principle

providing learners with feedback on their
metacognitive activities helps them to develop
and improve metacognition

(H. W. Lee, Lim, &
Grabowski, 2010; Roll
et al., 2006)

(Snow, McNamara, et al.,
2015; Verpoorten et al.,
2014)

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Review

(4) To what extent is metacognitive instruction controlled by the system or by the learner?

extended practice and assessment principle	providing learners with enough time, prolonged training, and frequent opportunities to assess comprehension is required for learners to develop and automate metacognition	(Azevedo et al., 2012; Bannert & Mengelkamp, 2013; Lin, 2001; Osman & Hannafin, 1992; Veenman et al., 2006)	
learning cycle principle	supporting all three SRL-phases of planning, performance, and evaluation is required for learners allows learners to apply evaluation outcomes to subsequent phases and helps them to develop and improve metacognition	(Zimmerman & Tsikalas, 2005)	(Nietfeld & Shores, 2011)

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

intrinsic integration principle	integrating learning goals and activities with gameplay goals and activities ensures that engaging with the gameplay becomes equivalent with engaging in learning	(Arnab et al., 2015; Carvalho et al., 2015; Habgood, 2007; Habgood & Ainsworth, 2011; Ke, 2016)	(Verpoorten et al., 2014)
alignment principle	aligning game activities and goals with learning activities and goals ensures that engagement resulting from gameplay is directed at initiating and sustaining learning	Chapter 1: Introduction (Amory, 2007; Arnab et al., 2012, 2015; Bedwell et al., 2012; Carvalho et al., 2015; Hung & Van Eck, 2010; Lim et al., 2013)	

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

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(Rieber, 1996; Squire,
2006)

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Table E.2: design dimensions for gameplay.

Design Dimensions for Gameplay		Background		
<i>design principle</i>	<i>definition</i>	<i>metacognitive training (in general)</i>	<i>game-based learning (in general)</i>	<i>game-based metacognitive training (in specific)</i>
(1) To what extent does the game involve social or individual interactions?				
individual practice principle	as metacognitive development differs between individuals, learners benefit from individual and personalized training	(Veenman et al., 2006)		(Mayer, 2016)
social incentive principle	social incentives are generally effective at engaging learners with gameplay as well as learning content	(Ryan & Deci, 2000) ⁴	(Barab, Dodge, Tuzun, Job-Sluder, et al., 2007; Steinkuehler & Tsaasan, 2019; Ter Vrugte et al., 2015)	
social identification principle	social identification, or modeling one's behavior after that of another learner, is an effective mechanism to promote metacognition;	(Hartman, 2001b)	(Malone, 1981)	(Kim et al., 2009; White & Frederiksen, 1998)
social reinforcement principle	social reinforcement, or the increased likelihood of engage in in behavior as observed in other learners, is an effective mechanism to encourage learners to engage in activities	(Bandura, 1977, 1986) ⁴ (Zimmerman, 1990)	(Malone, 1981)	

⁴ These references are shown in the column on metacognitive training in general, but refer to learning in general and not necessarily pertain to metacognition.

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

collaboration principle	using collaboration between peer learners and/or supervisors and using the affordances of GBL for adding collaboration with virtual companions are effective ways to help learners to develop and improve metacognition		(Nietfeld & Shores, 2011; Usart et al., 2011; White & Frederiksen, 2005, 1998)
competition principle	competition with other players is an effective mechanism to promote motivation through social incentive and as an additional challenge;	(Burguillo, 2010) ⁴	(Malone & Lepper, 1987; Romero et al., 2012; Sanchez, 2017; Ter Vrugte et al., 2015)
collaboration/competition principle	a combination of intragroup collaboration and intergroup competition is an effective mechanism to encourage learners to initiate and sustain gameplay activities		(Plass et al., 2015; Sanchez, 2017) (Ke, 2008b, 2008c)

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

game mechanics motivation and learning principle	the challenges and objectives, actions and responses, and feedback can pertain to gaming, to learning		(Arnab et al., 2015; Carvalho et al., 2015; Ke, 2016; Malone & Lepper, 1987)
game flow principle	through playing a game, the player will become better at the playing the game and to maintain sufficient challenge (while avoiding boredom and anxiety), gameplay must increase in difficulty as the player progresses (theory of flow)		(Hamari et al., 2016; Paras & Bizzocchi, 2005; Schell, 2019)
challenge motivation and learning principle	challenge provided by the system affects learning through increased engagement as well as directly		(Hamari et al., 2016; Malone & Lepper, 1987) (Sun-Lin & Chiou, 2017)

cognitive load principle	complex gameplay involving choices with many possibilities must be avoided to avoid cognitive overload of the learner	(Veenman et al., 2006)	(Azevedo et al., 2012; Kalyuga & Plass, 2009)
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(4) To what extent is the game fidelitous to or fictitious about representing the target learning situation?

narrative motivation and learning principle	the narrative setting and plot can provide motivation through curiosity as to what has happened or will or could happen next, while at the same time using metaphor and analogy to provide a cognitive framework supporting learning	(Barab et al., 2005; Dickey, 2019; Malone & Lepper, 1987; Van Oostendorp & Wouters, 2017)
realism principle	metacognitive training, and in particular pedagogical agents, in games need not be perceptually realistic to be effective	(Mayer, 2016)

Appendix F

Learning strategies

Overview of the learning strategies implemented in GBLEs in Design Experiments #2 and #3 as discussed in Chapter 6.

Table F.1: learning strategies implemented in Design Experiment #2 and #3.

Strategy	Description	DE#2	DE#3
Skim	Looking over a text to get a general overview of the material	V	
Highlighting	Reading through a text while marking the important information	V	
Rehearsing	Practice the learning materials, e.g., repeatedly writing down a formula to help you remember	V	
Practice testing	Test how many of the learning materials you actually know by making assignments or taking a practice exam	V	
Keyword mnemonics	Making a rhyme, song or an acronym out of the information to make it easier to remember	V	
Summarizing	Writing a summary of the learning materials	V	
Elaborative interrogation	Question yourself on why an explicitly stated fact or concept is true	V	
Self-testing	Ask yourself questions about the learning materials and try to answer them without looking at the answers	V	
Self-consequentiating	Think of ways in which you can reward or punish yourself for success or failure during the learning process	V	V
Self-evaluating	Going over your work to check the quality	V	V
Seeking information	Gathering information pertinent to the topic you study	V	V
Seeking social assistance	Asking another person for help, either online or in real life	V	V

Keeping records	Taking notes while writing or reading sources	V	V
Reviewing records	Rereading notes or the txt you have produced so far	V	V
Outlining	Making an outline of the main points, as preparation for writing a paper or detailed reading of a text	V	V
Imagery	Draw a picture, diagram, or flowchart to visualize the information that you want to understand or transfer	V	V
Environmental structuring	Finding a quiet place to work by isolating yourself from anything that may be distracting	V	V
Organizing	Ordering your notes or your source materials		V
Revising	Modifying your text or plans for writing		V
Self-monitoring	Checking to see if your writing goals are met, to verify whether you are on track		V
Self-verbalizing	Saying dialogue out loud while writing or articulating what needs to be done		V
Self-selecting models	Emulating the tactics or style of writing of a more gifted author		V
