chapter seven

General Discussion

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

1. Introduction

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

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

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

2. Key Insights and Implications

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

2.1 Rationale and Overview

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

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

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

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

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

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

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

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

2.2 Key Findings and Implications

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

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

Interdisciplinary State of the Art

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

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

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

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

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

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

Design Framework

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

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

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

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

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

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

Design Knowledge

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

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

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

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

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

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

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

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

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

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

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

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

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

3. On Game-Based Metacognitive Training

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

3.1 Towards a Design Process for Game-Based Metacognitive Training

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

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

Step 1: identifying and defining the desired outcomes

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

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

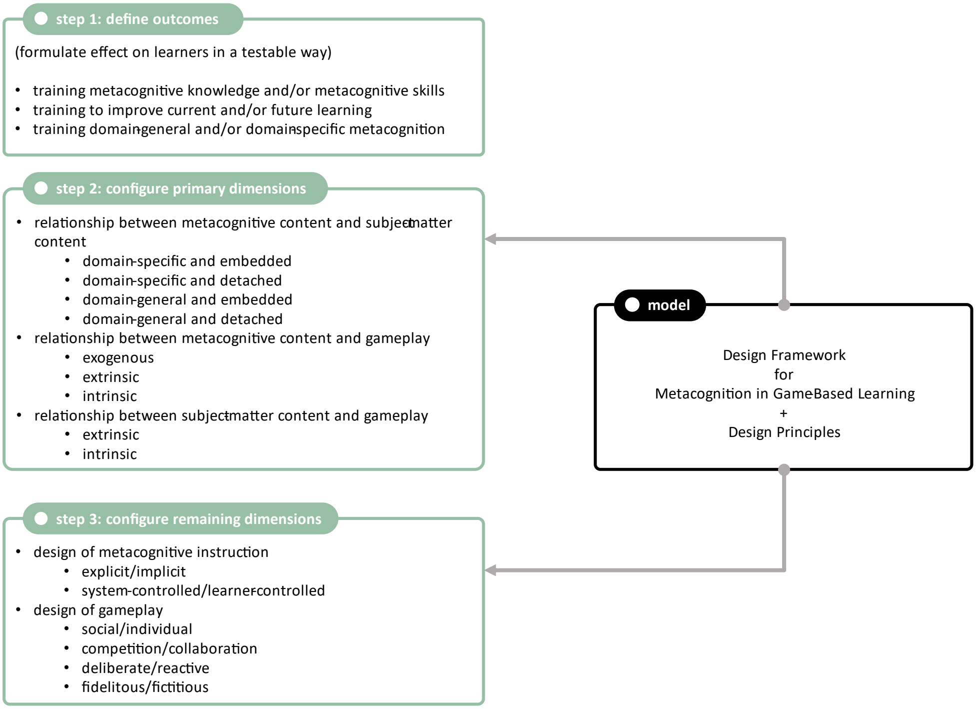

Figure 7.1: Overview of design process steps, options at each step, and its relation to the provided design framework and design principles.

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

Step 2: configuring the primary dimensions of the framework

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

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

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

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

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

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

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

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

Step 3: configuring the remaining dimensions of the framework

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

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

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

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

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

3.2 Towards a Theoretical Model of Game-Based Metacognitive Training

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

Reconsidering Metacognition

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

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

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

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

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

Reconsidering Game-Based Learning

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

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

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

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

Combining Metacognition with GBL

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

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

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

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

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

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

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

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

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

4. On Educational Design Research

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

4.1 Learning from Designed Artefacts

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

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

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

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

4.2 Learning in the Real World

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

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

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

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

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

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

4.3 Types of Design Knowledge

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

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

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

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

5. To Conclude

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

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

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

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

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

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

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

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

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

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

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Graesser, A. C. (2017). Reflections on serious games. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 199–212).

Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *Journal of the Learning Sciences*, *20*(2), 169–206.

Hacker, D. J. (2017). The role of metacognition in learning via serious games. In R. Zheng & M. K. Gardner (Eds.), *Handbook of Research on Serious Games for Educational Applications* (pp. 19–40). Hershey, PA, USA: IGI Global.

Hammond, K. R. (1998). Ecological validity: Then and now. Retrieved from https://www.albany.edu/cpr/brunswik/notes/essay2.html

Harrison, G. M., & Vallin, L. M. (2018). Evaluating the metacognitive awareness inventory using empirical factor-structure evidence. *Metacognition and Learning*, *13*(1), 15–38.

Hartman, H. J. (2001). Developing students' metacognitive knowledge and strategies. In H. J. Hartman (Ed.), *Metacognition in Learning and Instruction: Theory, Research, and Practice* (pp. 33–68). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Holleman, G. A., Hooge, I. T. C., Kemner, C., & Hessels, R. S. (2020). The "real-world approach" and its problems: A critique of the term ecological validity. *Frontiers in Psychology*, *11*, 721.

Höök, K., & Löwgren, J. (2012). Strong concepts: Intermediate-level knowledge in interaction. *ACM Transactions on Computer-Human Interaction*, *19*(3), 1–18.

Hung, W., & Van Eck, R. (2010). Aligning problem solving and gameplay: A model for future research and design. In R. Van Eck (Ed.), *Interdisciplinary Models and Tools for Serious Games: Emerging Concepts and Future Directions* (pp. 227–263). IGI Global.

Järvelä, S., Malmberg, J., Sobocinski, M., & Kirschner, P. A. (2021). Metacognition in collaborative learning. In U. Cress, C. Rosé, A. F. Wise, & J. Oshima (Eds.), *International Handbook of Computer-Supported Collaborative Learning* (pp. 281–294). Springer.

Kautzmann, T. R., & Jaques, P. A. (2019). Effects of adaptive training on metacognitive knowledge monitoring ability in computer-based learning. *Computers & Education*, *129*, 92–105.

Ke, F. (2008a). A case study of computer gaming for math: Engaged learning from gameplay? *Computers & Education*, *51*(4), 1609–1620.

Ke, F. (2008b). Computer games application within alternative classroom goal structures: Cognitive, metacognitive, and affective evaluation. *Educational Technology Research and Development*, *56*(5–6), 539–556.

Ke, F. (2016). Designing and integrating purposeful learning in game play: a systematic review. *Educational Technology Research and Development*, *64*, 219–244.

Ke, F., Shute, V. J., Clark, K. M., & Erlebacher, G. (2019). An evolving design framework for game-based learning platforms. In F. Ke, V. Shute, K. M. Clark, & G. Erlebacher (Eds.), *Interdisciplinary Design of Game-Based Learning Platforms* (pp. 141–151). Springer.

Khaled, R., Lessard, J., & Barr, P. (2018). Documenting trajectories in design space: A methodology for applied game design research. In *FDG18: Foundations of Digital Games*. New York, NY, USA: ACM.

Kihlstrom, J. F. (2021). Ecological validity and "ecological validity." *Perspectives on Psychological Science*, *16*(2), 466–471.

Kolarić, S., Beck, J., & Stolterman, E. (2020). On the hierarchical levels of design knowledge. In *Proceedings of the Design Society: DESIGN Conference* (pp. 51–60). Cambridge University Press.

Krogh, P. G., & Koskinen, I. (2020). Drifting in four epistemic traditions. In *Drifting by Intention* (pp. 29–45). Cham, Switzerland: Springer.

Kuhn, D. (2000). Metacognitive development. *Current Directions in Psychological Science*, *9*(5), 178–181.

Lee, J., & Choi, H. (2017). What affects learner's higher-order thinking in technology-enhanced learning environments? The effects of learner factors. *Computers & Education*, *115*, 143–152.

Lin, X. (2001). Designing metacognitive activities. *Educational Technology Research and Development*, *49*(2), 23–40.

Liu, S., & Liu, M. (2020). The impact of learner metacognition and goal orientation on problem-solving in a serious game environment. *Computers in Human Behavior*, *102*, 151–165.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266.

Martinez-Garza, M. M., & Clark, D. B. (2017). Two systems, two stances: A novel theoretical framework for model-based learning in digital games. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 37–58). Springer.

Maton, K. (2009). Cumulative and segmented learning: exploring the role of curriculum structures in knowledge-building. *British Journal of Sociology of Education*, *30*(1), 43–57.

Mayer, R. E. (2016). The role of metacognition in STEM games and simulations. In H. F. O'Neil, E. L. Baker, & R. S. Perez (Eds.), *Using Games and Simulations for Teaching and Assessment: Key Issues* (pp. 183–205). New York: Routledge.

Merriënboer, J. J. G. Van, & Bruin, A. B. H. De. (2019). Cue-based facilitation of self-regulated learning: A discussion of multidisciplinary innovations and strategies. *Computers in Human Behavior*, *100*, 384–391.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. In *The Psychology of Learning and Motivation* (pp. 125–173). Academic Press.

Nelson, T. O., & Narens, L. (1994). Why investigate metacognition? In J. Metcalfe & A. P. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 1–25). Cambridge, MA, USA: MIT Press.

Nietfeld, J., & Shores, L. R. (2011). Self-regulation within game-based learning environments. In L. Annetta & S. C. Bronack (Eds.), *Serious Educational Game Assessment* (pp. 19–42). Sense Publishers.

Novak, K. (2017). It takes a guild – Social metacognition and collaborative creation of a learning organization: Massively multiplayer online game. In A. Stricker, C. Calongne, B. Truman, & F. Arenas (Eds.), *Integrating an Awareness of Selfhood and Society into Virtual Learning* (pp. 198–224). IGI Global.

Osman, M. E., & Hannafin, M. J. (1992). Metacognition research and theory: Analysis and implications for instructional design. *Educational Technology Research and Development*, *40*(2), 83–99.

Ouellette, M. A. (2019). “I’m controlling and composing”: The role of metacognition in The Incredible Machine. *InVisible Culture*, *30*.

Panadero, E., & Järvelä, S. (2015). Socially shared regulation of learning: A review. *European Psychologist*, *20*(3), 190–203.

Pannese, L., Morosini, D., Moore, A., & Pammer, V. (2012). User models and affective metacognitive scaffolding for adaptive games. In P. Felicia (Ed.), *Proceedings of the 6th European Conference on Games Based Learning* (pp. 649–652). Cork, Ireland: Academic Conferences.

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist*, *50*(4), 258–283.

Plass, J. L., Homer, B. D., Mayer, R. E., & Kinzer, C. K. (2019). Theoretical foundations of game-based and playful learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 3–24). Cambridge, MA, USA: The MIT Press.

Plomp, T. (2013). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *Educational Design Research* (pp. 10–51). Enschede: SLO.

Redström, J. (2011). Some notes on program/experiment dialectics. In *Nordic Design Research Conference*. Helsinki: Aalto University.

Ricker, A. A., & Richert, R. A. (2021). Digital gaming and metacognition in middle childhood. *Computers in Human Behavior*, *115*, 106593.

Sandoval, W. A. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*, *23*(1), 18–36.

Sandoval, W. A., & Bell, P. (2004). Design-based research methods for studying learning in context. *Educational Psychologist*, *39*(4), 199–201.

Scheel, A. M., Tiokhin, L., Isager, P. M., & Lakens, D. (2021). Why hypothesis testers should spend less time testing hypotheses. *Perspectives on Psychological Science*, *16*(4), 744–755.

Schellings, G., & Van Hout-Wolters, B. H. A. M. (2011). Measuring strategy use with self-report instruments: Theoretical and empirical considerations. *Metacognition and Learning*, *6*, 83–90.

Schraw, G. (1998). Promoting general metacognitive awareness. *Instructional Science*, *26*, 113–125.

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology*, *19*, 460–475.

Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review*, *7*(4), 351–371.

Shelton, B. E., & Scoresby, J. (2011). Aligning game activity with educational goals: Following a constrained design approach to instructional computer games. *Educational Technology Research and Development*, *59*(1), 113–138.

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, *64*(2), 489–528.

Slussareff, M., Braad, E., Wilkinson, P., & Strååt, B. (2016). Games for learning. In R. Dorner, S. Gobel, M. D. Kickmeier-Rust, M. Masuch, & K. Zweig (Eds.), *Entertainment Computing and Serious Games*. Springer.

Steiner, C. M., Kickmeier-Rust, M. D., Mattheiss, E., Göbel, S., & Albert, D. (2012). Balancing on a high wire: Adaptivity, a key factor of future learning games. In M. D. Kickmeier-rust & D. Albert (Eds.), *An Alien's Guide to Multi-Adaptive Educational Computer Games*. Informing Science Press.

Taub, M., Azevedo, R., Bradbury, A. E., & Mudrick, N. V. (2020). Self-regulation and reflection during game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of Game-Based Learning* (pp. 239–262). Cambridge, MA, USA: MIT Press.

Usart, M., Romero, M., & Almirall, E. (2011). Impact of the feeling of knowledge explicitness in the learners' participation and performance in a collaborative game based learning activity. In M. Ma, M. Fradinho Oliveira, & J. Madeiras Pereira (Eds.), *Serious Games Development and Applications* (pp. 23–35). Springer.

Van den Akker, J., Branch, R. M., Gustafson, K., Nieveen, N., & Plomp, T. (1999). *Design Approaches and Tools in Education and Training*. (J. Van den Akker, R. M. Branch, K. Gustafson, N. Nieveen, & T. Plomp, Eds.). Springer.

Veenman, M. V. J. J., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and Individual Differences*, *15*, 159–176.

Veenman, M. V. J. J., Van Hout-Wolters, B. H. A. M., & Afflerbach, P. (2006). Metacognition and learning: conceptual and methodological considerations. *Metacognition and Learning*, *1*, 3–14.

Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in Educational Theory and Practice* (pp. 277–304). Lawrence Erlbaum Associates.

Wouters, P., Van Nimwegen, C., Van Oostendorp, H., & Van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265.

Wouters, P., & Van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education*, *60*(1), 412–425.

Wouters, P., & Van Oostendorp, H. (2017). Overview of instructional techniques to facilitate learning and motivation of serious games. In P. Wouters & H. Van Oostendorp (Eds.), *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 1–16). Cham, Switzerland: Springer.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., … Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research*, *82*(1), 61–89.

Zepeda, C. D., Hlutkowsky, C. O., Partika, A. C., & Nokes-Malach, T. J. (2018). Identifying teachers' supports of metacognition through classroom talk and its relation to growth in conceptual learning. *Journal of Educational Psychology*, *111*(3), 522–541.

Zepeda, C. D., Richey, J. E., Ronevich, P., & Nokes-Malach, T. J. (2015). Direct instruction of metacognition benefits adolescent science learning, transfer, and motivation: An in vivo study. *Journal of Educational Psychology*, *107*(4), 954–971.

Zimmerman, B. J., & Campillo, M. (2003). Motivating self-regulated problem solvers. In J. E. Davidson & R. J. Sternberg (Eds.), *The Psychology of Problem Solving* (pp. 233–262). Cambridge University Press.

Zumbach, J., Rammerstorfer, L., & Deibl, I. (2020). Cognitive and metacognitive support in learning with a serious game about demographic change. *Computers in Human Behavior*, *103*, 120–129.