
chapter two

Research Methodology and Research Design

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

1. Introduction

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

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

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

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

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

In this work, we aim to investigate solutions within an educational context. We are not merely seeking to advance insights in GBL, we also aim to contribute concretely to improving learning by designing, implementing, and evaluating real-world GBLEs within real-world educational programs with real-world students. This has two consequences. First, evaluation of proposed solutions typically takes place in practice, i.e., in *real-world educational settings* as opposed to in laboratories. Consequentially, the study of educational interventions often involves a trade-off between representativeness (of the target environment) and isolation of confounding factors (quasi-experiment versus experiment). Most of all, we need to take into account that we want any outcome – both in knowledge and in practice – to be able to migrate from our specific situation and apply to other similar educational settings

(Brown, 1992). Second, the design and development of proposed solutions typically takes multiple iterations. Consequentially, the study of educational interventions often involves the creation and evaluation of half-solutions, prototypes, and intermediate steps, of which the lessons learned are translated to further shaping of the solution (McKenney & Reeves, 2012). The research in this dissertation is aimed at investigating the rationale underlying our designs (e.g., models, principles, guidelines). If we want to examine how learners are affected by our designs, we will need to realize the design in the form of a specific educational intervention (e.g., prototypes, products, artefacts) and study that intervention through evaluation. Therefore, we need structured ways of linking the generic models and principles that informed our design to the concrete artefacts that we evaluate. Furthermore, this emphasizes the need to not only seek to assess *whether* a particular intervention is effective, but rather seek to also, and predominantly, identify *why and how* it is or is not effective. In other words, we need to be able to design, develop, and evaluate our solutions in an iterative way.

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

2. Design Research

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

and effectiveness (Andriessen & Van Turnhout, 2023). As such, design research seems to meet our requirements for a methodology.

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

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

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

conducting an experiment to study working mechanisms can be considered forms of research for design, while at the same time representing traditional research methods.

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

2.1 Cycles

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

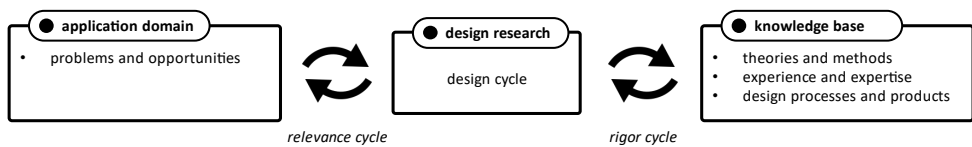


Figure 2.1: A three-cycle view of design research (Hevner et al., 2007; 2004).

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

concepts, and methods). This distinction has previously been characterized as *striving for utility* (as in effective artefacts) and *striving for truth* (as in justified theory) (De Villiers & Harpur, 2013; Fallman, 2007; Hevner et al., 2004), and can be compared to the concepts of a *context of discovery* and a *context of justification*, respectively (Hoyningen-Huene, 1987, 2006).

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

2.2 Phases

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

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

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

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

2.3 Questions

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

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

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

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

2.4 Methods

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

Analysis of Literature and Practice

An important initial step of design research involves assessing the state-of-the-art. Existing literature in general and existing solutions in specific represent relevant knowledge. We seek to collect this knowledge as generated by the research and designers that have previously addressed similar research and design questions. As discussed, however, the relevant literature is scattered across different disciplines and does not always directly concern the questions and contexts we are studying. Furthermore, this literature is fragmented and often concerns only part of our objectives. Therefore, translation (to our questions and context) and integration (of fragments of knowledge) need to occur before existing knowledge can be presented

in a form that is relevant to our research. The practical examples of GBLEs addressing similar issues will need similar translation and integration. Moreover, of such examples we would like to know how they are designed for their purpose – in other words, an additional step of deconstruction is needed to identify the relevant working mechanisms and underlying design principles. A structured qualitative literature review, aimed at identifying design knowledge, accommodates such collection and analysis of the current state-of-the-art in literature in practice.

Experiments to Test Hypotheses

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

Experiments to Construct Knowledge

An important part of constructing knowledge through design research involves conducting *design experiments*. Such experiments sample different possible design configurations and can quickly reject bad designs and thus increase the likelihood of finding good ones (Bang & Eriksen, 2014; Binder & Redström, 2006; Easterday et

al., 2014). Through the construction of artefacts, design researchers make propositions of 'what could be' (i.e., a proposed design configuration) and through the evaluation of such artefacts they make inferences towards 'what should be' (i.e., a preferred design configuration) (Binder, 2019; Zimmerman & Forlizzi, 2008). In this way, an artefact is a *prototype* of some imagined final product: it allows exploration of some aspects of that future artefact without completing all other relevant aspects. In particular, it allows a focus on exploring the most relevant open design questions (Houde & Hill, 1997).

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

2.5 Outcomes

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

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

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

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

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

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

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

3. Research Design

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

3.1 Research Scope

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

3.2 Research Objective and Main Question

With our research we seek to achieve two objectives:

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

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

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

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

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

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

3.3 Research Flow and Outline

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

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

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

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

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

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

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

In Chapter 5 (see Figure 2.2, top right), we present an experiment that focuses on the design of digital metacognitive instruction. We first derive a conceptual model of metacognition during self-regulated learning and, together with the design

framework from Chapter 4, use it to inform the design of a digital tool. This digital tool introduces self-explication as a metacognitive mechanism. The experiment in this chapter concerns the effectiveness of this mechanism to improve metacognition and learning, as well as the perceptions learners have on using such a tool. Furthermore, we explore whether a domain-general and detached approach to metacognitive training is viable.

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

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

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

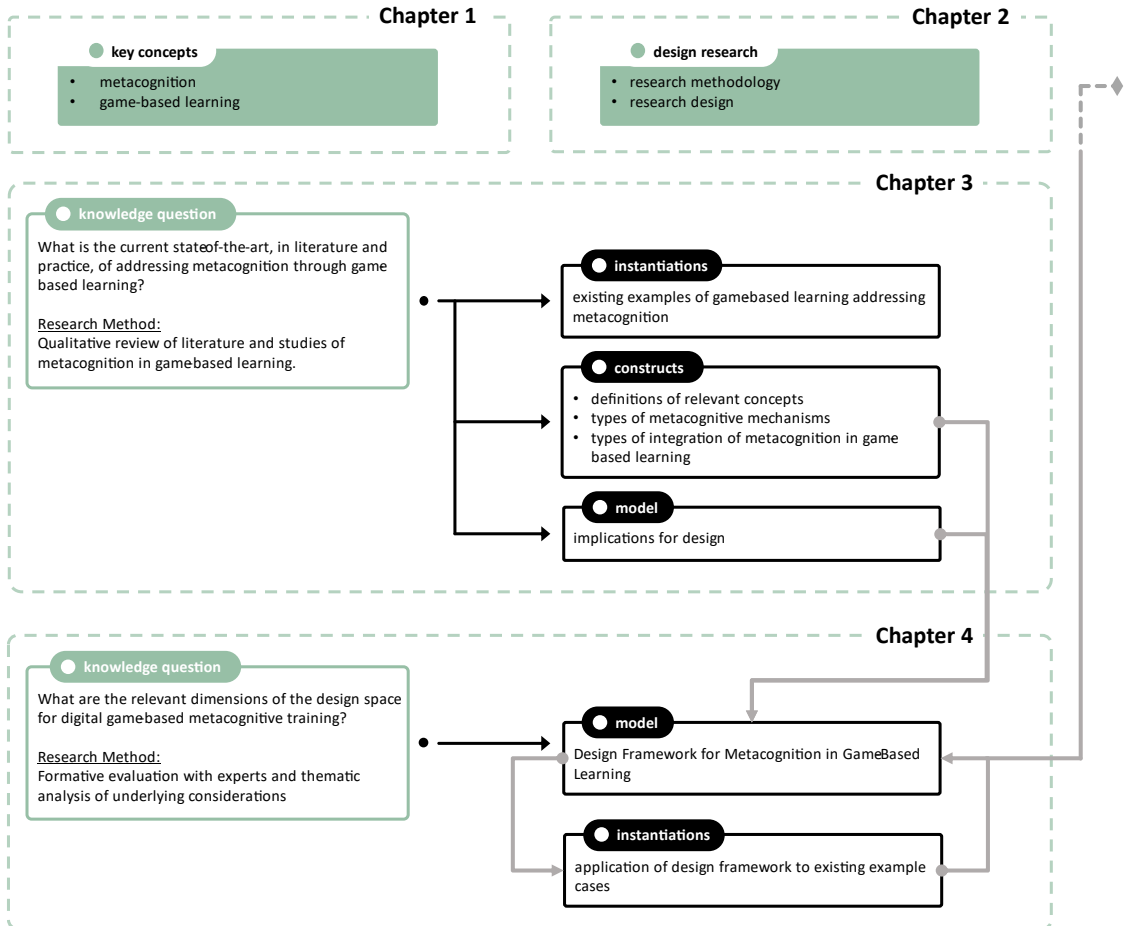
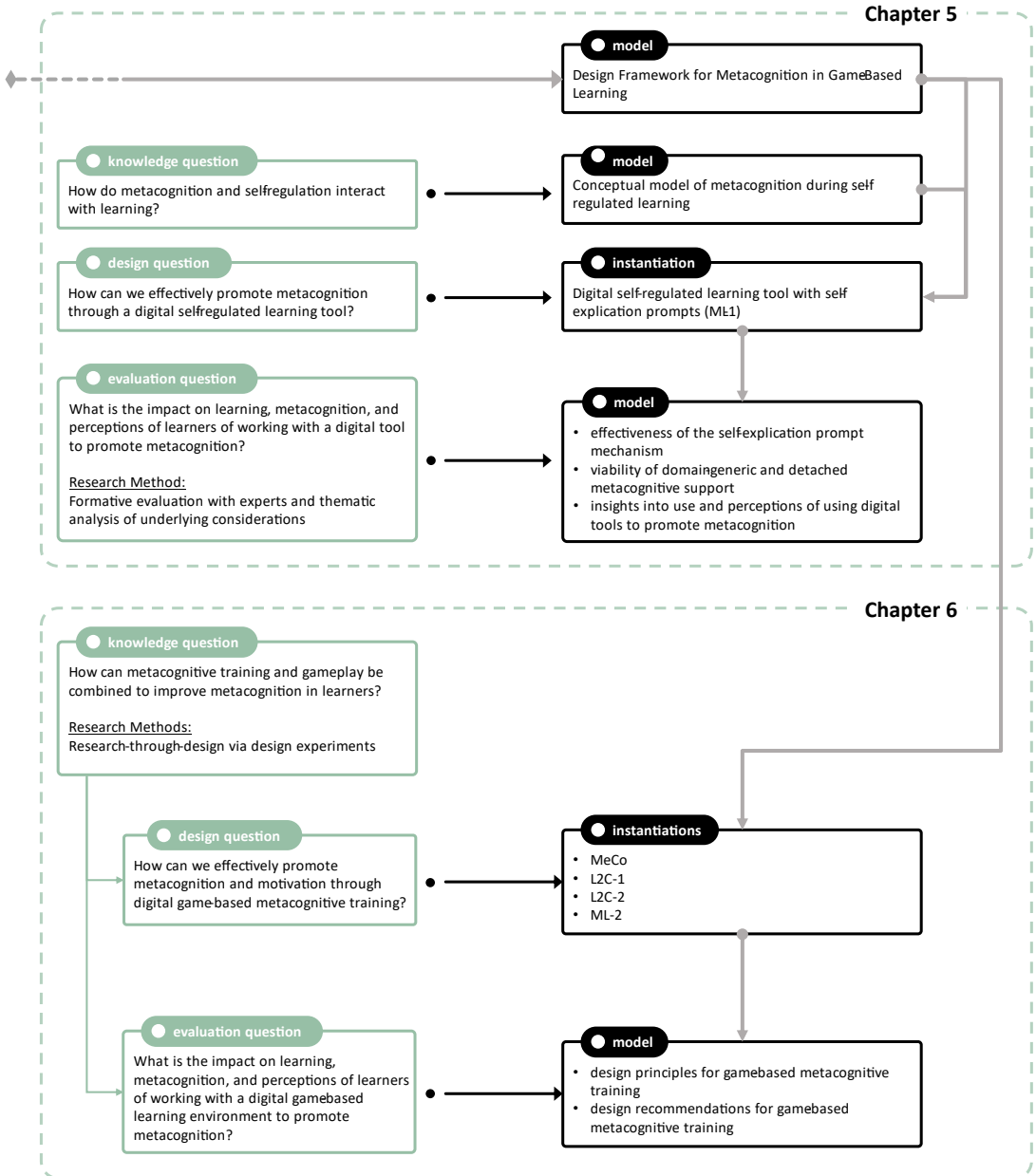


Figure 2.2: research flow.



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