Towards a Framework for Metacognition in Game-Based Learning

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Abstract: Game-based learning can motivate learners and help them to acquire new knowledge in an active way. However, it is not always clear for learners how to learn effectively and efficiently within game-based learning environments. As metacognition comprises the knowledge and skills that learners employ to plan, monitor, regulate, and evaluate their learning, it plays a key role in improving their learning in general. Thus, if we want learners to become better at learning through game-based learning, we need to investigate how metacognition can be integrated into the design of game-based learning environments.

In this paper we introduce a framework that aids designers and researchers to formally specify the design of game-based learning environments encouraging metacognition. With a more formal specification of the metacognitive objectives and the way the training design and game design aims to achieve these goals, we can learn more through analysing and comparing different approaches. The framework consists of design dimensions regarding metacognitive outcomes, metacognitive training, and metacognitive game design. Each design dimension represents two opposing directions for the design of a game-based learning environment that are likely to affect the encouragement of metacognitive awareness within learners. As such, we introduce a formalised method to design, evaluate and compare games addressing metacognition, thus enabling both researchers and designers to create more effective games for learning in the future.

Keywords: game-based learning, games for learning, metacognition, design-based research

1. Introduction

Over two decades of research have demonstrated that game-based learning can motivate learners and help them to achieve particular learning outcomes (Hainey et al., 2016; Wouters et al., 2013). One of the key approaches is to harness motivation and instruction into an integrated design, such that 'play' aligns with 'learning' (Habgood & Ainsworth, 2011). Consequently, game design methods and game design models are increasingly able to help designers to make informed design choices (Braad, Žavcer, & Sandovar, 2016).

However, within game-based learning environments, learners often struggle with learning efficiently and generally learners spend a lot of time on parts of the game that are not very relevant to learning (Ke, 2016; Wouters & Van Oostendorp, 2013). Learning within such non-linear and interactive learning environments requires a learner to know how to plan, monitor, and regulate learning (Azevedo et al., 2012), and these metacognitive knowledge and skills should be considered in the design of learning environments (Lin, 2001). Indeed, various reviews have pointed out the need for but also a lack of research into metacognition in relation to game-based learning (Ke, 2016; Sitzmann, 2011; Vlachopoulos & Makri, 2017). Thus, it is not always clear for learners how to learn effectively and efficiently by interacting with game-based learning environments, nor is it clear for designers how to effectively address these learner needs through the design a game-based learning environment.

1.1 Related Work

Game-Based Learning

Game-based learning refers to learning through interaction within a game-based learning environment. Within this game-based learning environment, gameplay is constituted by a rule-based system that presents challenges for a player, allows the player to perform actions to resolve these challenges, and offers feedback to indicate whether actions are effective towards the goals (Plass, Homer, & Kinzer, 2015). Games may contain motivating features, such as challenges and rewards, and can trigger intrinsically motivating experiences in players, such as curiosity, fantasy, cooperation, and competition (Dondlinger, 2007; Malone & Lepper, 1987). Games can support learning by allowing experimentation within a risk-free environment, by offering direct and indirect feedback to players, and by allowing players to reflect upon play through debriefing (Garris, Ahlers, & Driskell, 2002). As such, game-based learning seeks to harness the motivational characteristics of games to achieve the desired instructional objectives.

Metacognition in Learning

Since its conception as thinking about thinking, the definition of metacognition has been discussed among scholars, however, almost all current definitions include a combination of knowledge about and skills in acquiring new knowledge and skills (Jacobs & Paris, 1987; Schraw, 1998; Veenman, Van Hout-Wolters, & Afflerbach, 2006). In this paper we define metacognitive awareness as a learner's conscious understanding of how to use declarative, procedural, and conditional metacognitive knowledge to metacognitively plan, monitor, and evaluate learning (Schraw, 1998). We also contend with Schraw (1998) and Veenman et al. (2006) that metacognitive knowledge has domain-specific and domain-general aspects and can be trained. Such metacognitive training can focus on increasing awareness, understanding, and ability (i.e. to remediate a knowledge deficiency) or on increasing self-initiated use and accuracy in practice (i.e. to remediate a production deficiency) (Schraw, Crippen, & Hartley, 2006; Veenman et al., 2006).

Metacognition in Game-Based Learning

While much of research in game-based learning has focused on the acquisition of cognitive and skill-based learning outcomes, various reviews have pointed out the need and opportunity for investigating metacognitive outcomes as well (Ke, 2016; Sitzmann, 2011; Vlachopoulos & Makri, 2017). However, only a few studies have focused on encouraging metacognition in game-based learning (e.g. Fiorella & Mayer, 2012; Ke, 2008; Kim, Park, & Baek, 2009). Initial attempts to identify general research directions and design guidelines have been put forward for game-based learning in science, technology, engineering, and mathematics (Mayer, 2016), and from the broader perspective of self-regulation (Nietfeld & Shores, 2011). However, a recent and comprehensive review of metacognition in game-based learning found that current research is largely presented as stand-alone cases (Braad, Degens & IJsselsteijn, 2020). This makes it hard to compare different approaches and identify effective design principles to improve the design of future game-based learning environments.

1.2 Outline

The goal of this paper is to introduce a design framework that aids designers and researchers to formally specify the design of game-based learning environments encouraging metacognition. As a first step, in this paper we will focus on the question of which aspects in the design of game-based learning environments affect the promotion of metacognitive awareness.

2. Metacognitive Training/Game Design Framework

In this section we introduce the metacognitive training/game design framework. We will discuss three different areas of metacognitive game-based training design: metacognitive training objectives, metacognitive training design, and metacognitive game design. For each area, we will present a number of relevant and salient design dimensions: two opposing directions for the design of a game-based learning environment that are likely to affect the encouragement of metacognitive awareness within learners.

2.1 Dimensions for Metacognitive Training Objectives

In this section, we introduce two design dimensions that help to specify the metacognitive training objectives of the game-based learning environment.

Domain-Specific versus Domain-General Metacognition

The dimension of domain-specific versus domain-general metacognition is defined as the extent to which the metacognitive training goals are limited to or extend beyond a particular domain of learning.

Consensus among researchers is that a large part of metacognitive objectives is specific to the domain of learning: learners acquire the metacognitive knowledge and skills within one area of learning and transfer to other domains of learning is limited (Veenman et al., 2006). For example, learning how to solve an equation is specific to the domain of mathematics, even if similar problem-solving steps may be used in other domains. However, some aspects of metacognition have been found to be general across a range of domains (Hartman, 2001a; Schraw, 1998; Veenman et al., 2006); a distinction characterised as knowledge within a domain and knowledge about oneself as a learner (Lin, 2001). For example, monitoring learning and judging the progression of learning works similarly regardless of the subject of learning, whereas problem-solving steps in mathematics are domain-specific. Therefore, an important choice in the design of a game-based learning environment that encourages metacognition is whether the objective is to improve metacognition within the current domain, or whether the objective is to improve general metacognition across different domains.

The benefit of training domain-specific metacognition is that the training can make use of the domain-specific training content and thus offer concrete opportunities to practice. However, the range of applications for domain-specific metacognition is more limited: the learner will not be prepared for similar learning situations in different domains. In contrast, domain-general metacognition may require more effort on the part of the learner, as there is a separate step to instantiate the general aspects to the specific learning situation. Nonetheless, domain-general metacognition has the potential of preparing learners for a wider range of learning situations, and if the objective is to enhance domain-general metacognition, the training must be designed in such a way that the transfer to different learning situation is encouraged (Osman & Hannafin, 1992).

Current Learning versus Future Learning

The dimension of current learning versus future learning is defined as the extent to which the metacognitive training goals are aimed at enhancing current learning or future learning.

The objective of metacognitive training can be to enhance current learning. For example, a prompt to self-explain current understanding can enhance the effectivity of physics training game (Fiorella & Mayer, 2012). This type of metacognitive objective can be defined as near transfer of metacognition, as the metacognitive knowledge and skills that are encouraged by the system are intended to be applied to current, ongoing learning. The objective of metacognitive training can, alternatively, be to enhance future learning. For example, when learners are instructed to use learning strategies for game-based learning, this can be effective in current but also in future learning (Kim et al., 2009). This type of metacognitive objective can be defined as far transfer of metacognition, as the metacognitive knowledge and skills that are encouraged by the system are intended to transfer to future learning situations.

The transfer to future learning situations can transcend two different types of boundaries. First, a future learning situation may occur at a later point in time, but still lie within the same domain of learning. In this case, domain-specific training may be used, but the training must be designed to encourage self-regulated application of metacognition within the domain. Second, a future learning situation may lie within a different domain of learning, at a later time. In this case, domain-specific training is insufficient, and training must be designed in such a way that the metacognitive knowledge and skills that can be transferred are easily identified as such by a learner (a.o. see Osman & Hannafin, 1992).

2.2 Dimensions for Metacognitive Training Design

In this section, we introduce four design dimensions that help to specify the training design elements of the game-based learning environment with respect to the metacognitive training objectives.

Embedded versus Detached Training

The dimension of embedded versus detached training is defined as the extent to which metacognitive training content is embedded within or detached from domain-specific training content.

Embedded training of metacognition is often recommended, as the concrete context of domain-specific learning makes it easier for learners to connect metacognitive knowledge and skills to learning (Bannert & Mengelkamp, 2013; Veenman et al., 2006). For example, within a game-based learning environment that teaches electrical and computer engineering, a specific set of problem-solving steps may be implemented to guide learners to identify what they already know, what they want to know, and what they have solved so far (Tang, Shetty, & Chen, 2012). However, these steps only apply to a specific set of problems and are presented in a way that emphasises the application to this domain-specific learning situation. Detached training of metacognition separates metacognitive knowledge and skills from the domain-specific learning content. For example, learners may be instructed to adopt a particular learning strategy before playing a serious game (Kim et al., 2009). Detached training makes it easier for learners to identify aspects of metacognition that can be used in different learning situations, and thus encourages the transfer of metacognition to different domains and beyond current learning situations.

Explicit versus Implicit Training

The dimension of explicit versus implicit training is defined as the extent to which explicit instruction is provided to learners.

Explicit training of metacognition offers learners direct instruction on metacognitive knowledge and skills. The direct instruction of metacognitive strategies for game-based learning is one example (Kim et al., 2009). Consensus among researchers is that metacognitive training should be combined with explaining to learners why metacognition is important and beneficial (Bannert & Mengelkamp, 2013; Veenman et al., 2006). This can also be considered as explicit training, since it is directly communicated to learners why metacognition is encouraged. Implicit training of metacognition offers learners support for and feedback on the metacognitive knowledge and skills as they practice the application of metacognition to learning. For example, implicit supports such as gradually fading scaffolds, response prompts cueing self-explication or self-explanation, or metacognitive feedback may be implemented to encourage and improve metacognition, without providing explicit instruction to a learner.

As explicit training is concrete about what is expected from a learner, it leaves less room for a learner to self-initiate and practice metacognition. In other words, explicit training may be employed to address a knowledge deficiency, but may prove to be less effective in addressing a production deficiency. Likewise, implicit training may not be as effective to enhance metacognitive understanding, but could encourage learners to apply previously learnt metacognitive knowledge and skills. Therefore, it is advised that explicit training is used for novice learners, whereas implicit training is used for advanced learners (Osman & Hannafin, 1992). This is exemplified by the rationale underlying gradually fading scaffolds: if the learner needs less help, scaffolds should be removed and eventually should become unnecessary (Arroyo et al., 2014).

System-Controlled Training versus Learner-Controlled Training

The dimension of system-controlled versus learner-controlled training is defined as the extent to which the system or the learner determines when, what, and how metacognition is encouraged.

System-controlled training decides on behalf of the learner when and how training proceeds, and what is being trained. For example, a learner may be prompted to describe their current learning strategy at a system-decided moment (Castronovo et al., 2018). Such a system-controlled approach can be effective as a training environment that models the desired behaviour by example. However, this may prevent learners from learning when metacognitive processing is needed. Learner-controlled training allows learners to decide when and how training proceeds, and what is being trained. For example, offering a structured learning diary to document and reflect upon learning strategies allows a learner to self-initiate metacognitive processes before a cue reminds them to do so (e.g. Adcock, Watson, & Morrison, 2008).

It is hard for designers to strike the right balance between system-control and learner-control, since individual learners have different needs for metacognitive training at different times during learning. While a human teacher may guide a learner from overt external guidance towards covert or overt self-guidance (Hartman, 2001b), where such a teacher is unavailable, systems can attempt to adapt to perceived learner needs by varying the timing or explicitness of instruction (Azevedo et al., 2012).

Extrinsically Integrated versus Intrinsically Integrated Training

The dimension of extrinsically versus intrinsically integrated training is defined as the extent to which metacognitive training content is integrated with the gameplay.

Extrinsically integrated training situates metacognitive training content and interventions outside of the core gameplay. For example, gameplay revolving around the manipulation of electrical circuits may be augmented with paper worksheets on which learners can explicate the relation between in-game manipulations and real-world principles of physics (e.g. Fiorella & Mayer, 2012). Intrinsically integrated training situates metacognitive training content and interventions as part of the core gameplay. For example, within an adventure game, metacognitive estimations of confidence can be embedded within the narrative setting, the non-playing characters, and the puzzles (e.g. Verpoorten et al., 2012).

Various studies have shown that learning and motivation increase when an intrinsically integrated design was employed (Habgood & Ainsworth, 2011; Vandercruysse & Elen, 2017). Intrinsic integration, while admirable, is compromised by issues relating to cognitive load, timing of feedback for learning and playing, and learner control (Graesser, 2017). Moreover, as metacognition refers to a learner's own understanding of and skills in monitoring and regulating learning, it is not straightforward to extend the principle of integrated design from domain-specific training games to metacognitive training. In the next section, we will introduce design dimensions that aid the integration of metacognitive training in the game design.

2.3 Dimensions for Metacognitive Game Design

In this section, we introduce five design dimensions that help to specify the game design elements of the game-based learning environment with respect to the metacognitive training objectives.

Competitive versus Cooperative Gameplay

The dimension of competitive versus cooperative gameplay is defined as the extent to which agents work against each other or together towards their goals.

Competition is a straightforward way of creating conflict through game design and is often named as one of the primary ways in which games offer challenges to players (Malone & Lepper, 1987): by competing against the game itself (e.g. in puzzle games), against computer players (e.g. in race games), or by competing against other players (e.g. in battle games). Competitive play provides a clear challenge, as the goal of the game is immediately evident, and players are rewarded based on how well they perform within the game as compared to the opposition. Cooperation is based on rewarding working together with other agents (i.e. players or non-playing virtual characters) to achieve the goals of the game – whether these are the same or different goals. However, this distinction is not undisputed: competition and cooperation could be integrated elements of a game design that work together towards motivation and learning (Sanchez, 2017).

Both competition and cooperation have been associated with learning (e.g. Burguillo, 2010), however, in relation to game-based learning, results are mixed. In one study, while learning effects did not differ between competitive or cooperative gameplay conditions, an effect was found for different learners: whereas below-average students suffered from competition, above-average students benefited from competition in terms of knowledge gains (Ter Vrugte et al., 2015). In another study, no effects of an individualistic, competitive or cooperative classroom goal structure on metacognition were found (Ke, 2008). As for metacognitive objectives, research currently lacks sufficient evidence to advise for or against competitive or cooperative play, or a combination thereof.

Reactive versus Deliberate Gameplay

The dimension of reactive versus deliberate gameplay is defined as the amount of time available to players to respond to the challenges the game provides.

Reactive gameplay requires players to respond relatively quickly to the changes in the game environment. For example, in racing games players need to adjust throttle and steering to efficiently navigate a vehicle around a track in the fastest possible way, and in dancing games players need to quickly perform the correct moves on

the beat of a song. Deliberate gameplay, in contrast, allows players to take their time to respond to the game. For example, puzzle games often allow players to consider the next move at leisure, as do turn-based simulation games.
This dimension is related to more physical versus more mental play (cf. Schell, 2015, p. 151). In this conception, physical and reactive play encourages unconscious processing while mental and deliberate play encourages conscious processing. As training metacognitive awareness is aimed at increasing conscious understanding of planning, monitoring, regulating, and evaluating learning, it seems that deliberate gameplay is more suitable for metacognitive training than reactive play. However, further research is needed to confirm such a hypothesis.

Real-World versus Fantasy

The dimension of real-world versus fantasy is defined as the extent to which the game-based learning environment is similar to the target learning situation.

This dimension can be thus conceptualised as the fidelity of the game environment with respect to the real-world. Rooney (2012) distinguishes between two types of fidelity as physical fidelity (the extent to which the game environment appears as the real world) and functional fidelity (the extent to which the game environment acts like the real world). For example, the virtual characters depicted as two-dimensional comic characters serve as learning advisors to the player in Inquiry Island (White et al., 2002) do not offer much physical fidelity, but do provide functionally meaningful and applicable advice that aid metacognitive processing. Likewise, a realistic three-dimensional environment may be more physically fidelitous (McQuiggan & Hoffmann, 2008), but still needs to maintain a functional fidelity to be effective at encouraging metacognition. Mayer (2016) suggests that pedagogical agents need not be perceptually realistic at all to be effective, unless that is the instructional objective.

While fantasy has long been recognised as a major way in which games can engage players (Dondlinger, 2007; Malone & Lepper, 1987), too much fantasy may hamper learning, as the transfer of in-game metacognitive learning to real-world learning situations becomes harder for learners to make. Metaphors, however, can provide an elegant way to link fantasy narrative design aspects to learning, by providing clear analogies between in-game playing and real-world learning (Charles, Hanna, Paul, & Charles, 2012). Another example is to adopt the topic of learning itself as the main theme of the game, as is done in the Analects of Confucius (Sung, Hwang, Lin, & Hong, 2017). Thus, the balance between real-world and fantasy game environments revolves around providing enough fantasy to engage players and enough situatedness to allow transfer to real-world learning situations.

Individual versus Social Gameplay

The dimension of individual versus social gameplay is defined as the extent to which the gameplay involves social interactions with other players.

Individual gameplay refers to a single player interacting with the game-based learning environment. As metacognitive awareness refers to a learners own understanding of and skills in learning, benefits of individual training are that a learner can choose her own pace, receive feedback on her own metacognitive knowledge and skills, and generally learn to self-initiate metacognitive processing. Furthermore, individual training lacks social comparisons, which may provide an increased sense of safety for learners to experiment and risk failure.
Social gameplay refers to the broad category of players interacting within or outside of the game-based learning environment during learning. The social context of game-based learning can improve fun, challenge, and perceived competence (Gajadhar, De Kort, & IJsselsteijn, 2008), and was found to be one of the three most important factors that enhance the effectiveness of game-based learning (Wouters et al., 2013). Benefits of social gameplay to metacognition include the need to explicate strategies, tactics, and actions in discussion with other learners. Furthermore, learners may observe and model other learners (Kim et al., 2009) and encounter different approaches to learning previously unknown to them.

Although social gameplay to enhance metacognition has been studied, no clear positive effects of social interactions or social features within games on metacognition were found, and further research is needed to identify the benefits and drawback of individual and social gameplay (Braad, Degens & IJsselsteijn, 2020).

Performance Rewards versus Learning Rewards

The dimension of performance versus learning rewards is defined as the extent to which the incentive system within the game rewards increased performance or increased learning effort within learners.

An incentive system that rewards performance is common to many games and may contribute to learning. For example, awarding points for successful actions in the game (Lin & Chiou, 2017) or awarding a higher position on a leader board for more successful players (Nebel et al., 2017) enhanced learning. An incentive system that rewards learning instead of performance is much less common in game-based learning design. However, rewarding effort over performance, and new strategy use over success increased learner persistence when confronted with failure (O'Rourke et al., 2016).

The difference between striving for performance or for learning is strongly related to metacognition. Dweck (1986) relates a learner's own beliefs about intelligence to different achievement goal orientations: whereas some learners prefer to demonstrate current competence (belief that intelligence is fixed; performance orientation), others seek to improve mastery by actively seeking failure and learning by reflecting upon mistakes (belief that intelligence is malleable; mastery orientation). Emphasising different achievement goals within game-based learning affects in-game behaviours and player motivation (Heeter et al., 2011). For example, mastery-oriented learners were found to more often self-induce help-seeking than performance-oriented learners (Arroyo et al., 2014). However, further research is needed to identify how to promote mastery, in addition to performance, within game-based learning environments.

3. Discussion

The goal of this paper was to introduce a design framework that helps designers and researchers to more formally specify the design of game-based learning environments from the perspective of metacognition. As the first step, we focused on identifying relevant and salient design dimensions that are likely to affect metacognitive awareness. We have highlighted two dimensions for defining the metacognitive training objectives, four dimensions for metacognitive training design, and five design dimensions for metacognitive game design. For each dimension, we have provided a working definition and motivated its relevance for metacognitive training design. Furthermore, we have provided examples of games that represent different positions within each dimension. As such, we have highlighted how the framework could be used to specify existing game-based learning environments that encourage metacognition.

Within some of the dimensions, previous research provides insights that can aid designers to make informed design decisions. For example, it seems plausible that deliberate (versus reactive) gameplay is more suitable for metacognitive training. However, in most dimensions, current research lacks the evidence to provide designers with guidelines for designing better game-based learning environments that encourage metacognition. For example, whether social interactions (versus individual gameplay) enhance metacognition needs further research. As such, the framework and its dimensions may be used to formulate future research directions and hypotheses.

3.1 Limitations

In this paper, we have not explicitly discussed the role of instructional support to enhance metacognition. However, through the dimensions for metacognitive training, in particular system- versus learner-controlled training and extrinsically versus intrinsically integrated training, such metacognitive interventions can be accommodated by the framework.

Currently, the framework is built on insights from literature and practice. However, we have not yet verified the usefulness of the presented dimensions in the analysis, comparison and design of game-based learning environments. The next step in developing this framework is to invite experts from different fields to discuss the proposed framework and its application to design and research. Another future step in the development this framework would be to identify how each design dimension affects learning, where outcome variables such as current and future domain learning, metacognitive knowledge and skill, as well as motivational factors need to be considered.

3.2 Conclusions

The design dimensions for outcomes, training design, and game design provide a first step towards being more specific about metacognition in game-based learning. It supports designers and researchers in specifying the metacognitive objectives and the way in which the game-based learning environment is designed to achieve these goals.

While we have regarded the design dimensions from the perspective of metacognition and game-based learning, we recognise that our approach could be adapted to a wider range of digital training tools and training outcomes. We foresee that a framework such as this does need to be specific to the metacognitive learning outcomes: it may be applied to and prove useful for the analysis, design, specification, comparison of games and other digital training tools with different cognitive purposes – and hence could be generalized towards this purpose.

In summary, we believe this framework contributes to structuring advances in game-based learning within this new area of inquiry, and eventually will benefit designers and researchers in improving metacognition through game-based learning.

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