Design Experiments in Game-Based Learning of Metacognition

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Abstract: Learner metacognition is one of the most influential factors that positively affects learning. Previous work shows that game-based learning can contribute to supporting and developing metacognitive knowledge and skills of learners. While there are many specific examples of such games, it remains unclear how to effectively design game-based learning environments to achieve this in an effective way. In other words: there is sufficient case-specific evidence, but limited design knowledge derived from such cases. In this paper, we attempt to identify such intermediary design knowledge that resides between specific games and generalized theory. We present three design experiments where game-based metacognitive training is evaluated in real-world educational settings. We collected insights regarding usefulness, motivation, usage, effort, and metacognition among participating students. From these experiments we identify what was learned in the form of design recommendations and, as such, contribute to collecting intermediary design knowledge for designing game-based metacognitive training.

Keywords: Game-Based Learning, Metacognition, Design experiments, Design research

1. Introduction

One of the most influential determinants of efficient and effective learning is metacognition: the knowledge a learner has about how they acquire new knowledge and the skills to use that knowledge to monitor and regulate learning (Brown, 1978; Flavell, 1976; Veenman, Van Hout-Wolters, & Afflerbach, 2006). However, metacognition is not equally developed in al learners and does not commonly develop autonomously (Veenman, Elshout and Busato, 1994; Veenman, Van Hout-Wolters and Afflerbach, 2006). Providing learners with metacognitive training seems an effective way of improving their current and future learning skills and, in turn, their learning performance.

Such metacognitive training must be *active* (to combine development of knowledge and skills with practice), *engaging* (to ensure learners exert the additional effort over a longer period of time) and *self-contained* (to allow learners to use an intervention regardless of the context and as they see fit). Game-Based Learning (GBL) could satisfy these practical needs. Indeed, various reviews of GBL have proposed to further investigate how metacognition can be impacted through GBL (Sitzmann, 2011; Ke, 2016; Hacker, 2017). However, current insights are limited to specific case-by-case findings and it remains unclear how to effectively design game-based learning environments (GBLEs) to achieve this in an effective way (Braad, Degens and IJsselsteijn, 2019, 2020). In other words: there is sufficient case-specific evidence, but only limited design knowledge derived from such cases.

In this paper, we attempt to identify such intermediary design knowledge that resides between specific games and generalized theory (Höök & Löwgren, 2012). We present a series of three design experiments. Each design experiment focuses on a particular prototype: a proposition of 'what could be' (i.e., a proposed design configuration). The role of this prototype is thus predominantly as a vehicle for inquiry and focused on quickly rejecting bad designs and thus increasing the likelihood of finding good ones (Binder & Redström, 2006; Bang & Eriksen, 2014; Easterday, Lewis and Gerber, 2014; Wensveen & Matthews, 2014). The prototype is evaluated in real-world educational settings to make inferences towards 'what should be' (i.e., a preferred design configuration) (Zimmerman & Forlizzi, 2008). The evaluations focus on (1) usefulness and motivation to use, (2) usage and perceived effort, and (3) metacognition and strategies.

Throughout the design experiments, we sample the design space with instantiations and from these experiments we identify and formalize what was learned in the form of design recommendations. As such, we contribute to collecting intermediary design knowledge for designing game-based metacognitive training.

2. Design Experiment #1

2.1 Design

This design experiment studies a GBLE that combines learning of metacognition with motivation through gameplay as two separate parts. The learning part uses the self-regulated learning cycle to encourage learners to reflect and adapt their learning process (Zimmerman & Campillo, 2003).

To allow use of the GBLE with any type and content of learning, the design of the GBLE makes no assumptions about what is being learned but, crucially, prompts learners to self-explicate learning goals, activities, and strategies and to evaluate these afterwards (Braad *et al.*, 2022). The GBLE does provide learning strategies adapted from Zimmerman & Schunk (1989), Schraw (1998), and Dunlosky *et al.*, (2013). Through engaging in the metacognitive activities, learners earn virtual currency in the form of gold, which can be spent in the gaming part of the GBLE to advance. As such, the GBLE rewards the effort a learner puts into metacognitive monitoring and regulation with an advantage in the game.

The gaming part is based on Space Invaders (Taito, 1978), where the player needs to defeat wave after wave of opponents by shooting at them. In the gaming part, virtual currency buys upgrades to increase winning odds and advance levels. The game unlocks learning strategies, which can be used for planning. As such, the game links progress in the gaming part to additional options in the learning part.

2.2 Evaluation

The study was conducted over one session with all participants present (8 students in higher education, 3 female, 5 male, aged 20-25 years). Participants were informed of the objectives and procedure of the study and received a 30-minute introduction explaining the relevant features of the GBLE. The participants then worked for 60 minutes with the GBLE as they saw fit. Finally, the participants took 15 minutes to complete a self-report questionnaire and participate in an interview.

2.3 Results

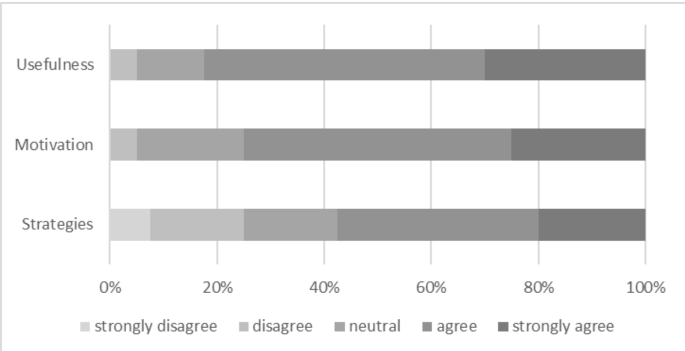

Figure 1: Participant perceptions of usefulness, motivation, and relevance of strategies offered through the GBLE

Usefulness and motivation

The results of the questionnaire are shown in Figure 1. More than half of the participants (strongly) agreed it was useful and multiple participants mentioned improved insight in estimating and planning time for learning:

> *"I learned that tasks take a lot longer than you expect. Planning specific time when to study is very useful."*

> *"Scheduling your time and finding out and using new or a variety of learning strategies can be useful and fun."*

While none of the participants strongly disagreed with the GBLE providing motivation, interviews revealed that some participants found the game too difficult to play. Suggestions for improving motivation included altering the game loop, making the game more visually appealing, and incorporating social features into the game. One participant found the gameplay mostly distracting from learning:

> *"I think it's a bit silly that you have to play a game before you can get new strategies. This disturbed my attention and distracted me".*

Metacognition and strategies

Regarding metacognition, on average participants were satisfied with the applicability of the provided learning strategies. However, some participants struggled to use the GBLE when the available strategies could not be meaningfully applied to current learning: "Not all learning strategies were applicable to what I was studying. I couldn't really implement one". Most participants reported becoming more aware of which strategies may be effective, however, only two participants said they had tried out a new strategy and only one participant agreed that they had found new ways to learn.

2.4 Conclusions

In conclusion, this GBLE design has some potential to motivate learners and affect metacognition. We learned that the extrinsic integration of metacognitive instruction with gameplay, in this design experiment, appears to be a two-edged sword: it may engage learners who would otherwise not perform metacognitive activities, but risks disengaging learners who otherwise would perform them. Participants suggested that, in addition to the individual approach, a social element could help to motivate learners. The training should also be more applicable to ongoing learning by providing relevant learning strategies. Overall, this design and evaluation warrant further research, as the suggested improvements of social features and more applicable strategies can be implemented with reasonable effort.

3. Design Experiment #2

3.1 Design

We further explore this design approach by addressing the suggested improvements and studying its use in a real-world learning context over a longer period of time. To address the need for a social element within the GBLE, we implemented a global leaderboard feature where learners could compare themselves to other learners in a competitive way. However, to avoid disengaging low achievers (cf. Ter Vrugte *et al.*, 2015), the incentive structure was designed to encourage trying out new and different learning strategies, rather than to encourage learning performance directly (cf. O'Rourke *et al.*, 2014). The position on the leaderboard was based on the number of different learning strategies used and, as such, provides a social incentive to try out different strategies. To address the need for more applicable strategies we added learning strategies specific to this group's writing assignment.

3.2 Evaluation

This experiment was conducted among a group of *N*=40 students (33 female, 5 male, and 2 unspecified), aged 19-29 (*M*=22.1, *SD*=1.9). To assess learners' perceptions of working with this GBLE, a similar self-report measure as in the previous design experiment was used to assess motivation, usefulness, use of learning strategies, and required effort. Quantitative log data from the GBLE were used to trace learner activities. The metacognitive awareness inventory (MAI; Schraw and Dennison, 1994) was used in the pre-test and post-test to measure participants' awareness of metacognitive knowledge and skills during learning. During the four-week period, a weekly lecture was scheduled, with the final hour designated for working with the GBLE. Students could use the GBLE as they saw fit during these sessions or at any other time.

3.3 Results

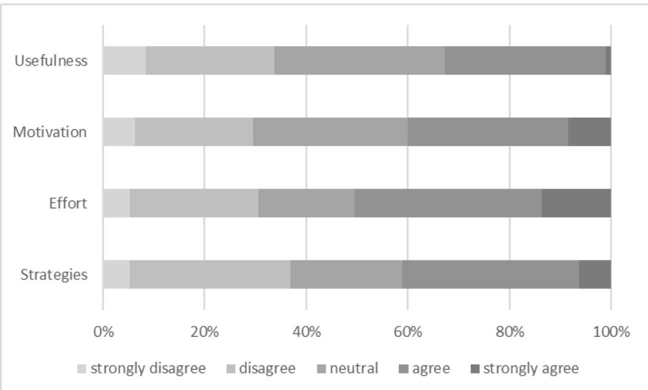

Figure 2: Participant perceptions of usefulness, motivation, required effort and relevance of strategies offered through the GBLE

Usefulness and motivation

Some participants found the GBLE useful for their own learning process, however, multiple participants indicated that the GBLE would be more useful for first year students:

> *"[It] provides a designated environment where you stay on top of your project."*

> *"I liked using the app to log my activities and see how much time I spent studying."*

> *"For people who do not yet have a clear idea of how to learn, it's probably very useful because it allows them to try out different strategies."*

Multiple participants found the game pretty fun and named playing the game and getting on the leader board as its best feature. In contrast, about the same number of participants found the gaming element frustrating:

> *"Time-consuming and not very useful for people who are not motivated by games"*

Usage and effort

On average, participants used the tool for up to 7.5 hours minutes (*M*=1.8, *SD*=2.0). Usage was spread over 1 to 10 distinct days (*M*=3.7, *SD*=2.7) and distributed over 1 to 28 sessions (*M*=8.0, *SD*=7.9). However, the gaming activities sometimes took more time than the actual studying effort itself:

> *"I spent way more time playing the game to earn new learning strategies than actually working on my essay. The game was fun, yes, but I feel like I wasted a lot of time on it."*

Metacognition

For some participants the GBLE helped to regard learning metacognitively, however, for multiple participants these insights were not new:

> *"It forced me to actively think about the ways in which I approach the assignment"*

> *"The strategies I did use were useful, but I was already aware of them and using them in my learning process."*

> *"It's not motivating to people like me who have established writing routines"*

Sometimes the provided strategies did not match the learning task:

> *"It is not that they were not useful, they just weren't useful for the part of the essay writing process that I was in at that moment."*

For the participants who completed both the pre-test and the post-test (*N*=12), a one-tailed paired-samples t-test indicated no significant increase in metacognitive awareness between pre-test and post-test, *t*(12)=.640, *p*=.268, *d*=.185.

3.4 Conclusion

The GBLE was generally considered to be of added value, in particular to organize learning into goals and activities, and to plan and time learning activities. Learners were now able to meaningfully apply the available strategies to their learning process. The extrinsic integration of learning and playing was received positively in general, even when a simple type of gameplay was used. However, the leaderboard that was introduced as a social incentive to increase motivation played only a limited role in motivation to use the GBLE. As in the previous design experiment, this design worked for the majority of learners, however, others viewed the game as an obligatory waste of time.

Measures of use of the GBLE, both in terms of frequency and duration, indicated participants did use the GBLE regularly and both in response to cues (during the sessions) and, to a lesser extent, in a self-initiated way (outside of class). This corroborates the results for usefulness and motivation of the GBLE.

We did not find a significant increase in metacognition. Some participants were encouraged to think about their approach to learning, and a few tried a different approach than before, but unfortunately without much satisfaction. Thus, while most participants could now meaningfully apply the provided strategies to their ongoing learning, this brought them few new insights. The use of this GBLE was mostly recommended for more novice learners, indicating a potential mismatch between the support offered by the system and the need for support as perceived by learners.

In conclusion, we learned that this GBLE design may have potential to motivate learners and affect metacognition, if the effort involved in both learning and in playing can be reduced, while at the same time motivation to use and keep using the GBLE can be improved.

4. Design Experiment #3

4.1 Design

The previous two design experiments showed potential for combining self-explication with GBL. However, we also found that use of such GBLEs is limited in duration as well as frequency, and use occurs mostly in response to external cues. Furthermore, we learned that not all learners are motivated by games and some regard the effort required for gaming activities as superfluous to learning. Therefore, in this final design experiment, we explore a design that promotes motivation to initiate and sustain use of the GBLE, while not demanding the effort of playing through a game as in the previous design experiments.

To support learners' metacognition throughout the SRL-phases of preparation, performance, and appraisal, four features were implemented: goals, methods, plans, and a logbook. Each feature included an open prompt to avoid providing too much or too little guidance. For example, the goals feature allowed leaners to specify their goals during learning via the prompt: "What are you trying to accomplish? Which objectives in learning do you have? Here, you can keep track of your goals." The methods feature allowed learners to specify the different ways of learning they use, while the plans feature enabled them to formulate relevant learning activities and link them to their goals and methods. The logbook feature allowed learners to record relevant occurrences during learning, with some events automatically added.

To incentivize use of the GBLE, we combined game design elements of varying complexity (Deterding *et al.*, 2011) to appeal to different forms of extrinsic and intrinsic motivation (Przybylski, Rigby and Ryan, 2010; Proulx, Romero and Arnab, 2017). Users could form groups, chat, and earn badges for completing activities within the GBLE. The badges were displayed in bronze, silver, and gold when unlocked and in black when not yet unlocked. Group members could view each other's badges and work together to collect them, fostering cooperation. The group's collective achievements were converted into a score displayed on a leaderboard. A dedicated forum allowed users to exchange insights, examples, and tips, as well as share their goals, methods, plans, or logbook entries for peer feedback.

4.2 Evaluation

The evaluation took place as a 9-week long in-vivo quasi-experiment, with students randomly assigned to either the intervention group using the GBLE or the comparison group not using the GBLE. The study adopted a within-subject pre-test/post-test design and mixed methods were used to collect data.

The study was conducted among 12 undergraduate 1st-year classes. Participants in nine randomly selected classes were assigned to the intervention group with N=39 students completing the experiment (26 male; 13 female; aged 16-26, M=19.4, SD=2.0). The comparison group consisted of N=15 students (9 male; 6 female; aged 18-28, M=20.1, SD=2.6).

The measures taken during this study were collected through a pre-test questionnaire, focus group sessions, log data from the GBLE, and a post-test questionnaire. The MAI was used to assess metacognition (Schraw & Dennison, 1994; Harrison & Vallin, 2018). A researcher introduced the study and metacognition in the first week and administered the pre-test questionnaire. Students used the GBLE for eight weeks, with weekly reminder emails. Two focus groups were organized in the second week and the post-test questionnaire was administered in the final week.

4.3 Results

Perceptions and motivation

The results from the participants who did use the GBLE indicate that they did not enjoy using it and found that using it involved too much effort. This could be partly due to limited guidance on how to use the GBLE:

> *"I did not understand at all what to write down at the method part, so maybe give examples."*

Some participants found that the goals-, methods-, and plans-features contributed positively to learning by providing structure and control:

> *"When there were a lot of deadlines and I felt overwhelmed, writing it all down helped"*

The results from the participants who did not use the GBLE indicate that motivation did not play an important role in their choice. Instead, required effort (too high) and perceived usefulness (too low) were important reasons to not make use of the GBLE. Some participants felt overwhelmed altogether:

"I was too busy with assignments and learning to use the tool as well"

A few participants did not find the GBLE useful for themselves. The game features implemented to promote use and sustained use of the GBLE did not convince participants to use it. However, the reason for not using the GBLE that was most often given was simply forgetting about it:

"There was no bigger motivation behind the tool. The achievements were not enough of a reward"

"I initially wasn't too interested in using the tool and eventually forgot about it"

Usage

We analyzed data for N=29 participants who used the GBLE according to the log data. On average, these participants used the tool for up to 125 minutes (M=17.5, SD=27.1). Usage was spread over 1 to 5 distinct days (M=1.3, SD=.1) and distributed over 1 to 5 sessions (M=1.8, SD=1.2), with the majority of participants using the GBLE only on a single day and in a single session. Only 5 groups were formed involving only 11 of the users. Use of the forums was limited to 11 posts and 6 replies among 8 of the users. Only a few of these interactions related to learning, while most were initial messages to see how this feature worked.

Metacognition

We conducted a mixed factorial ANCOVA with the experimental condition as a between-subjects factor and the pre-test metacognitive awareness scores as a covariate. No significant effect of the experimental condition itself was found while accounting for pre-test scores, $F(1,51)=.319$, $p=.575$, $\eta^2=.006$. One-tailed paired-sample t-tests were then conducted on the pre-test/post-test contrasts of metacognitive awareness per group. In the intervention group (N=39), metacognitive awareness significantly increased between pre-test and post-test, $t(38)=2.077$, $p=.023$. The increase in the comparison group (N=15) was not significant, $t(14)=1.607$, $p=.065$.

4.4 Conclusions

On average, use of the GBLE over the experimental period was very limited in frequency: most participants used it only a few times. Duration of use varied widely and up to two hours in total, however, was limited to a quarter of an hour on average. Social interaction in terms of group-forming or interactions via forums was also very limited. We found a substantial drop-out of participants during the study but could not explain this in terms of a priori metacognition or motivation. Altogether, we can conclude that a potentially positive effect of using the GBLE on metacognition was not achieved for most students. The limited use of the tool, in terms of frequency and duration, prevents any strong conclusions regarding its effects on metacognition.

Although we found no indications of problems with the explicit system prompts and otherwise high amount of learner control, it remains unclear whether learners were able to use the GBLE in a productive way. Perhaps additional instructions and scaffold could have worked towards learning how to use the GBLE in a step-by-step way. For example, the feature regarding methods of learning seemed more difficult to use productively, and perhaps offering a few pre-made learning strategies could have improved its use. Moreover, additional cues within the GBLE, but also within the classroom, may have helped learners to use the GBLE more regularly and more productively. Altogether, in the present study our limited cues were insufficient to initiate use of the GBLE, as were the mechanisms within the GBLE to sustain it.

5. Discussion

We will first provide our recommendations as identified across these design experiments. We will then conclude the paper with suggestions for future research.

5.1 Design Recommendations

We recommend the following when designing GBLEs for metacognitive training:

- Make metacognitive support as relevant as possible to ongoing domain-specific learning – for example by suggesting strategies that are specifically relevant for current learning goals and activities. When domain-specific learning content is also taught within the GBLE, embed metacognitive training within this content of the GBLE: this makes the transfer easier and makes the support more relevant.

- When adopting a domain-general approach make sure that additional support helps learners to make the far transfer from metacognitive training to real-world learning. The mechanisms to promote transfer of metacognition to learning should be explicit and should be presented apart from gameplay to emphasize their different role.
- Inform users explicitly, beforehand, about the purpose and potential benefit of using the GBLE as this increases interest as well as the potential of transfer of metacognition to learning. Explicitly address learning in terms of the goals, activities, and strategies it involves. This can also be done in a summary after an episode of gameplay.
- Explicitly instruct and encourage learners to make use of the available metacognitive support features within the GBLE. Implement support features that cue the use of the available support.
- Consider learners' experience with learning and vary explicit instruction and implicit support accordingly. Consider the amount of effort involved in student control of the metacognitive support. Avoid superfluous effort and hard thinking without discernable benefits.
- When integrating metacognition with gameplay, be careful about the balance between time spent on game activities and on learning activities. Relate the gameplay loop to learning activities to benefit motivation as well as learning.
- Incorporate social interactions within the GBLE as these can work to promote motivation as well as metacognition. Explain and point out the use of social interactions within the GBLE and how these contribute to learning to encourage learners to make use of these.
- Avoid competition between learners on indicators of learning or metacognition: such performance-based competition is likely to disengage all but the high-ranking learners. Instead, seek for indicators of effort, novelty, and exploration of learning.
- Choose a deliberate type of gameplay that avoids time pressure and promotes thinking and reflection – in particular when striving to integrate metacognition with the gameplay. This allows players to reflect on choices and speculate on alternative outcomes.
- Alternate between metacognitive activities and gameplay activities to allow learners to engage in these activities from a different cognitive stance.

5.2 Conclusions and Future Work

Research of domain-specific GBL recommends intrinsic integration of learning content with gameplay. However, our design experiments indicate that such intrinsic integration is not similarly effective when training metacognition through gameplay. Previous research discusses similar issues when integrating such reflective activities with gameplay (Sabourin *et al.*, 2013; Verpoorten *et al.*, 2014). Correspondingly, approaches that more explicitly differentiate between gameplay and reflection thereupon have been shown to be effective (Fiorella & Mayer, 2012; Castronovo, Van Meter and Messner, 2018). This leads us to wonder whether intrinsic integration of metacognitive training with gameplay is possible or even desirable. Due to their different focus of learner attention, a disconnection between learning and playing may be necessary to facilitate game-based metacognitive training.

As metacognition requires a learner to inspect and adjust their own learning, it may be useful to reflect this different focus of attention in the design of the GBLE. The complexity of integrating metacognitive support with gameplay is to combine the "doing" associated with experiential learning of GBL with the "thinking" associated with metacognition. The stance adopted when learning, playing, problem-solving, could be inherently different from the stance adopted when monitoring, strategizing and reflecting (Martinez-Garza & Clark, 2017). In this sense, metacognition is at odds with experiential learning and requires an extra step beyond the context of the game – "breaking the fourth wall", if you will – for real-world learning to be affected. We conjecture that learning may additionally involve a metacognitive stance (a state of mind aimed at optimizing learning itself).

Future research should focus on resolving the complexities of combining learning, gameplay, and metacognition. With combined effort, and taking advantage from our learnings, future design and future research may find more sophisticated ways of improving metacognition through GBL.

References

Bang, A.L. and Eriksen, M.A. (2014) 'Experiments all the way in programmatic design research', *Artifact*, III(2), pp. 4.1-4.14.

Binder, T. and Redström, J. (2006) 'Examplary design research', in Friedman, K. et al. (eds) *Wonderground - DRS International Conference*.

Braad, E. *et al.* (2022) 'Improving metacognition through self-explication in a digital self-regulated learning tool', *Educational Technology Research and Development*.
Braad, E., Degens, N. and IJsselsteijn, W.A. (2019) 'Towards a framework for metacognition in game-based learning', in Elbaek, L. et al. (eds) *Proceedings of the 13th European Conference on Games-Based Learning*. ACPI.
Braad, E., Degens, N. and IJsselsteijn, W.A. (2020) 'Designing for metacognition in game-based learning: A qualitative review', *Translational Issues in Psychological Science*, 6(1), pp. 53–69.
Brown, A.L. (1978) 'Knowing when, where, and how to remember: A problem of metacognition', in Glaser, R. (ed.) *Advances in Instructional Psychology (Volume 1)*. New Jersey, USA: Lawrence Erlbaum Associates, pp. 77–165.
Castronovo, F., Van Meter, P.N. and Messner, J.I. (2018) 'Leveraging metacognitive prompts in construction educational games for higher educational gains', *International Journal of Construction Management*, 22(1), pp. 19–30.
Deterding, S. *et al.* (2011) 'From game design elements to gamefulness: Defining gamification', in *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments*. ACM, pp. 9–11.
Dunlosky, J. *et al.* (2013) 'Improving students' learning with effective learning techniques', *Psychological Science in the Public Interest*, 14(1), pp. 4–58.
Easterday, M.W., Lewis, D.R. and Gerber, E.M. (2014) 'Design-based research process: Problems, phases, and applications', in Polman, J.L. et al. (eds) *Learning and Becoming in Practice: The International Conference of the Learning Sciences (ICLS) 2014*. Colorado, CO, USA: International Society of the Learning Sciences, pp. 317–324.
Fiorella, L. and Mayer, R.E. (2012) 'Paper-based aids for learning with a computer-based game.', *Journal of Educational Psychology*, 104(4), pp. 1074–1082.
Flavell, J.H. (1976) 'Metacognitive aspects of problem solving', in Resnick, L. B. (ed.) *The Nature of Intelligence*. Hillsdale, NJ: Erlbaum, pp. 231–235.
Hacker, D.J. (2017) 'The role of metacognition in learning via serious games', in Zheng, R. and Gardner, M.K. (eds) *Handbook of Research on Serious Games for Educational Applications*. Hershey, PA, USA: IGI Global, pp. 19–40.
Harrison, G.M. and Vallin, L.M. (2018) 'Evaluating the metacognitive awareness inventory using empirical factor-structure evidence', *Metacognition and Learning*, 13(1), pp. 15–38.
Höök, K. and Löwgren, J. (2012) 'Strong concepts: Intermediate-level knowledge in interaction', *ACM Transactions on Computer-Human Interaction*, 19(3), pp. 1–18.
Ke, F. (2016) 'Designing and integrating purposeful learning in game play: a systematic review', *Educational Technology Research and Development*. Springer US, 64, pp. 219–244.
Martinez-Garza, M.M. and Clark, D.B. (2017) 'Two systems, two stances: A novel theoretical framework for model-based learning in digital games', in Wouters, P. and Van Oostendorp, H. (eds) *Instructional Techniques to Facilitate Learning and Motivation of Serious Games*. Springer, pp. 37–58.
O'Rourke, E. *et al.* (2014) 'Brain Points: A growth mindset incentive structure boosts persistence in an Educational game', in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 3339–3348.
Proulx, J.-N., Romero, M. and Arnab, S. (2017) 'Learning mechanics and game mechanics under the perspective of self-determination theory to foster motivation in digital game based learning', *Simulation & Gaming*, 48(1), pp. 81–97.
Przybylski, A.K., Rigby, C.S. and Ryan, R.M. (2010) 'A motivational model of video game engagement.', *Review of General Psychology*, 14(2), pp. 154–166.
Sabourin, J.L. *et al.* (2013) 'Understanding and predicting student self-regulated learning strategies in game-based learning environments', *International Journal of Artificial Intelligence in Education*, 23(1–4), pp. 94–114.
Schraw, G. (1998) 'Promoting general metacognitive awareness', *Instructional Science*, 26, pp. 113–125.
Schraw, G. and Dennison, R.S. (1994) 'Assessing metacognitive awareness', *Contemporary Educational Psychology*, 19, pp. 460–475.
Sitzmann, T. (2011) 'A meta-analytic examination of the instructional effectiveness of computer-based simulation games', *Personnel Psychology*, 64(2), pp. 489–528.
Taito (1978) 'Space Invaders'. Atari.
Veenman, M.V.J.J., Elshout, J.J. and Busato, V.K. (1994) 'Metacognitive mediation in learning with computer-based simulations', *Computers in Human Behavior*, 10, pp. 93–106.
Veenman, M.V.J.J., Van Hout-Wolters, B. H. A.M. and Afflerbach, P. (2006) 'Metacognition and learning: conceptual and methodological considerations', *Metacognition and Learning*, 1, pp. 3–14.
Verpoorten, D. *et al.* (2014) 'A quest for meta-learning gains in a physics serious game', *Education and Information Technologies*, 19, pp. 361–374.
Ter Vrugte, J. *et al.* (2015) 'How competition and heterogeneous collaboration interact in prevocational game-based mathematics education', *Computers & Education*. Elsevier Ltd, 89, pp. 42–52.
Wensveen, S. and Matthews, B. (2014) 'Prototypes and prototyping in design research', in Rodgers, P. A. and Yee, J. (eds) *The Routledge Companion to Design Research*. Abingdon, UK: Taylor & Francis, pp. 262–276.
Zimmerman, B.J. and Campillo, M. (2003) 'Motivating self-regulated problem solvers', in Davidson, J.E. and Sternberg, R.J. (eds) *The Psychology of Problem Solving*. Cambridge University Press, pp. 233–262.
Zimmerman, B.J. and Schunk, D.H. (1989) *Self-Regulated Learning and Academic Achievement: Theory, Research, and Practice*. New York: Springer-Verlag.
Zimmerman, J. and Forlizzi, J. (2008) 'The role of design artifacts in design theory construction', *Artifact*, II(1), pp. 41–45.