Designing for Motivation:  
Design-Considerations for Spaced-Repetition-Based  
Learning Games on Mobile Devices

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Abstract: Learning games are an ideal vessel for many kinds of learning content. Playful interaction with the subject matter makes the human mind more receptive and thus learning itself more effective. Well designed games also come with an addictive game-play that makes users want to play the game over and over. This is intended in fun games but it can be counterproductive in learning games as users spend time with content they are already proficient with while they could use this time to learn other less familiar content. Spaced-repetition-learning is a learning approach that helps to improve retention with a minimal number of repetitions. It uses an algorithm based on psychological models to determine when to present a content item. This paper discusses design considerations from both the game-based and the spaced-repetition perspective to explore how the efficiency of spaced-repetition-learning can be combined with the fun and effectiveness of game-based learning.

Introduction

Learning games are widely seen as a way to distribute learning content in a motivating and engaging manner to the learners (Gee, 2003). This is on one hand due to the fact that today’s learners belong to the group of digital natives (people who have grown up with digital technology) and on the other hand owed to the fact that games by themselves are designed to be fun in the first place. Interactivity and a user-centered design enable students to have a “learning by doing” experience, which is far more immersive than just reading about a topic. Furthermore studies have proven that games especially foster abstract thinking and conceptual knowledge (Gee, 2003, Prensky, 2006, Kelly, 2005). However, weaving learning content into games is not an easy task. There are several design patterns which help and which therefore should be considered. These considerations are even more specific when bringing learning games to mobile devices. While traditional video games are played on computers or consoles and thus are subject to spending quite a huge amount of time with the game, mobile games are played in a rather fractional way and in short amounts of time. Those games should therefore be designed to be played occasionally and on the go.

Motivation is one of the key aspects when it comes to learning games according to de Freitas (2007). By keeping this factor on a high level, games are able to keep the players’ attention for a long period of time while they try to figure out a way to solve the given task and thus accomplish objectives. Furthermore they may then attract learners to play the game repeatedly, which is well in line with the “spaced repetition” approach which has its roots in the so called “spacing effect”. This states that repetitions of the same learning content, after a given amount of time, improve the retention of this content by flattening the forgetting curve (Ebbinghaus, 1885). Since then a lot of research has been done in order to find the best time between learning intervals to achieve the best possible results and hence the best relation between the time spent learning and the learning success. There are already some computer-based algorithms which try to determine these intervals by judging the learner’s performance and combining it with other factors like the number of repetitions. The omnipresence of mobile devices such as smartphones and tablets opens the door for learning almost anywhere and anytime and therefore fosters the spaced repetition learning approach even further. Reminders appearing on the mobile device’s screen enable learners to learn a content which is scheduled for repetition at just the right time. Studies have already shown that repeating learning content at certain intervals has a huge effect on long-term memorization (Ebbinghaus, 1885, Pimsleur 1967). This is the groundwork for immersing learning content and enabling learners to solve complex tasks afterwards.

Integrating the spaced repetition approach in mobile learning games therefore promises a huge potential for optimizing the learners’ performance. However, mobile learning games have to be specially
designed in order to achieve this goal. Spaced repetitions add a new dimension to the design process for a mobile learning game, since too much motivation to play the game several times in a row in a short amount of time would be in conflict with the spaced repetition approach. In this paper we present several design considerations which should be made with a special focus on mobile learning games and the area of conflict between them and the spaced repetition approach regarding the learners’ motivation.

The remainder of this paper is organized as follows. In the related work section we present the status quo of related fields of research and some basic design considerations for (mobile) learning games before we lead over to an overview about using spaced repetitions in mobile learning games. After that we discuss several design considerations that should be made when using the spaced repetition approach in those games and present ways how to overcome the arising conflicts. Finally, we draw a conclusion from our findings and give a forecast for future work.

Related Work

The question how learning games should be designed in order to foster learning has already been researched a couple of times. However, these researches have a slightly different focus because they do not consider the stress field between mobile learning games on one and the spaced repetition approach on the other side. What unites them is that almost all of them promote motivation as a key driver for a better learning success. According to Deci (1975) there are three classifications of motivation. While intrinsic motivation pushes people to act on their own and from their inside, extrinsic motivation pulls people to act due to external factors. Examples for the latter are rewards or threats. The third classification is the absence of motivation, called amotivation. In learning games one can often find intrinsic and extrinsic motivation coexisting and even a shift from extrinsic to intrinsic motivation over time.

There are several elements that are proven to have motivating effects on students. One of the most promising approaches is using narrative from which there are five occurrences according to Äyrämö (2011). In this paper we are focusing on the “story event-based approach” and the “game scenario-based approach”. Both approaches wrap the learning content in a surrounding story which is then presented to the learner. Dickey (2005) claims that this story should ideally provide a visual metaphor to the learners’ real-world knowledge in order to make it easier to understand the task’s meaning. Besides that, making the learning content blur with the game story is seen by Gómez-Martín et al. (2005) as a key concept for game-based learning.

Waraich (2004) adds that the learning tasks need to be “appropriately designed and tightly coupled with the narrative” in order to make the task meaningful to the user. On a downside Fisch (2005) notes that it is important to keep the learning content in focus. Otherwise learners may remember the appealing elements of the game better than the content itself.

Another important aspect to keep the motivation of the learners high is a well implemented interaction concept and therefore a system of rules, feedback and goals. The rules are usually derived from the respective content. For example in a game about electromagnetism called “Supercharged!” which was examined by Squire et al. (2004) the rules are connected to the physical rules of electromagnetism. Therefore in a game about for example database concepts, the rules will be derived from concepts and definitions from the database domain.

The game’s goals should be designed in a way that they are geared to the learner’s performance. At this point the spaced repetition approach comes into play. This concept stipulates that learning contents should be repeated at a specific rate. According to Pimsleur (1967) to achieve the best learning results, the intervals between repetitions should increase the better the learner achieves the respective goal. This was also supported by Wozniak (1994) when he developed SuperMemo\(^1\). He states on one hand that “Intervals should be as long as possible to obtain the minimum frequency of repetitions, and to make the best use of the so-called spacing effect, which says that longer inter-repetition intervals, up to a certain limit, produce stronger memories.” and on the other hand that “Intervals should be short enough to ensure that the knowledge is still remembered.”

In order to help students to learn even from their mistakes and to achieve the goals in further repetitions, the game environment should also provide a system of hints and feedback about the learners’ performance, according to Fisch (2005). This may include to provide the learners with information about mistakes they have made and what the right solution would have been.

Denis and Jouvelot (2005) differentiate game-based learning into edutainment and educational games. According to them the main difference between those two forms is interactivity. While educational games include a sophisticated system of rewards, goals and user engagement, “edutainment often fails in transmitting

\(^1\) http://www.supermemo.com
non trivial (or previously assimilated) knowledge, calling again and again the same action patterns and not throwing the learning curve into relief’’ (Denis and Jouvelot, 2005). However, that mentioned learning curve is closely connected to the forgetting curve which our approach of using spaced repetitions in mobile learning games tries to flatten. Therefore it is hard to draw a distinct line between edutainment and educational games in Denis’ and Jouvelot’s definition. Even edutainment games, which follow a more repetitive approach then the explorative approach used by educational games, are able to foster gains in learning as Lee et al. (2004) have proven when researching a math facts game for second graders. These gains should be fostered even more when following the principles of the spacing effect which is based on a repetitive practice. Therefore both kinds of learning games have a right to exist depending on the respective topic. What both have in common is that afterwards the learners should be able to apply what they have learned in real-world scenarios. Based on this, Garris et al. (2002) have developed the “Input-Process-Outcome Game Model”. We have taken this model and combined it with the spaced repetition approach which can be seen in figure 1.

In its original form, the “Input-Process-Outcome Game Model” is a regular cycle that includes a continuous loop of user judgments, user behavior and system feedback. After having injected the instructional content and the game characteristics, the learner judges what he gets presented. The result of that judgment should be things like interest or enjoyment, which keep him playing several rounds of the game and re-playing it in the future. This can lead to user behaviors like improved times to solve a task or greater persistence which may then influence the system feedback. If the game is designed properly, this cycle may result in self-motivated learning. After having played the game several times, the learner is able to apply the learned objectives, which corresponds to the concept of “doing, reflecting, understanding, and applying” as described by Kolb (1971). In Figure 1 we have combined the “Input-Process-Outcome Game Model” with the spaced repetition approach, which leads to different intervals (R1 to R5) between the learning sessions, i.e. playing the game.

**Spaced Repetition in Mobile Learning Games**

As it was shown, learning games represent a promising way for a better understanding and a better retention of a certain topic by the learners and thus immersing it. Following this strategy of immersing knowledge, the stage of system feedback in the modified “Input-Process-Outcome Game Model” (Figure 1) can very well be used to apply a spaced repetition algorithm to modify the game’s selection of learning content and thus further enhance the learners’ motivation by avoiding to select the same content several times in a row. Since the model is designed as a cycle, the injection of the re-scheduling can take place continuously.

The spaced repetition approach is already commonly used in fields like vocabulary training, which often relies on flashcards. The idea behind spaced repetition is to find an ideal interval between the repetitions for one learning item. According to Bahrick and Phelps (1987) these ideal intervals are the longest possible...
intervals that do not lead to forgetting. There are already several algorithms and applications available which try to calculate the optimal intervals between learning sessions. One of the most well known representations of them is SuperMemo and its SM2 algorithm. While there are already mobile implementations of these algorithms for vocabulary learning, it has not yet been used in game-based learning. We have already introduced two prototype mobile learning games which are based on the SM2 algorithm to schedule repetition for certain content at the optimal intervals (Schimanke et al., 2013a and 2013b).

While evaluating these prototypes we found out that using only the SM2 algorithm in this scenario is not appropriate since it is a strictly time-based solution. When using game-based learning, content creation usually takes more effort as the game should consist of a number of challenging and interesting tasks. Depending on the respective learning topic, there might be a limited amount of content which often leads the user to play several rounds of the game in a row. As described in Schimanke et al. (2013a) this will corrupt the spaced repetition concept since the algorithmically calculated time is not elapsed before the learner starts the next repetition. This might also affect the playing behavior. Due to the short term memory effect, the learners might produce too many correct answers in a short time. This would make the algorithm schedule the next repetition too far in the future which might keep the learner from using the game in the best possible intervals according to the spacing effect as can be seen in figure 2. Above the time bar one can see the intended repetitions as they are calculated by the algorithm. If the learner decides to play several rounds in a row (in this case four), the results of the last round are used to calculate the next repetition as can be seen below the time bar. Due to a usually better performance because of the short term memory effect, this would lead to a next scheduled repetition which is too far in the future and thus compromises the spaced repetition approach.

![Figure 2: Regular repetitions vs. compromised repetitions due to playing several rounds in a row](image)

Therefore we have developed the FS algorithm (Schimanke et al., 2013a) which is round-based and which takes over the content selection when the user decides to play one or more rounds after the initial, scheduled one. After the SM2 algorithm has selected the appropriate content after starting the game and re-scheduled the next repetition based on the learners’ performance, the FS algorithm is in charge to mimic the SM2-concept of ranking learning content by the level the learners already remember it in a round-based manner for the remainder of that game session. From the moment the FS algorithm takes over, there are no more values manipulated or re-schedulings done which would affect the integrity of the SM2 algorithm.

**Design Considerations**

Combining mobile learning games with the spaced repetition approach raises several questions concerning the design of those games. While traditional computer games and even learning games are usually played on stationary computers or consoles, mobile games are played today on smartphones or tablets. This circumstance itself already needs a different design approach. Adding the concept of spaced repetitions alters
this approach even further. While there has already been quite a lot of research about designing educational or learning games, there are currently no efforts combining these best practices in design with the special needs of mobile learning games which take advantage of the spaced repetition approach.

When designing a mobile learning game, there are several decisions to be made before thinking about the design itself. First, the type of the game has to be defined. This is usually strongly influenced by the respective learning topic. There is a wide range of possible options, ranging from simple learning card implementations or quizzes to complex augmented reality games and 3D worlds. While one type of a game might be appropriate for one learning topic, it might be inappropriate for others. Another consideration has to be made about the skills the game should teach. Anderson’s (2000) revision of Bloom’s taxonomy represents a good model to classify those skills. However, every kind of a learning game should always be designed to be motivating and engaging to the learners.

Davidsson et al. (2004) have published an extensive list of design patterns for mobile games which is based on a different hardware but which still applies to most of the mobile games today. Designing mobile learning games should take those design patterns in consideration as groundwork depending on the type of the game. As an addition, the current hardware used by today’s mobile learners should be taken in consideration. Most of those devices rely on touch displays to interact with the user and offer a wide range of technical options like for example gyroscopes, one or more cameras and GPS tracking which may also come into use in learning games.

When designing a mobile learning game, not all in chapter two mentioned aspects can or should be realized. Which aspects of the commonly seen best practices should be implemented always depends on the game itself and its purpose. For example there is no use designing 3D worlds for a game which intends to explain and immerse the concept of relational databases while this approach might suit very well for games which deal with more explorative contents like anatomy or biology. From our point of view it is also hard to draw a distinct line between edutainment games and educational games here like Denis and Jouvelot (2005) do, because different scenarios require different approaches. Especially when it comes to learning concepts it is often helpful to use the spacing effect and therefore spaced repetitions in order to immerse those concepts by repeating them at a sophistically determined interval (Kornell 2009).

However, the spaced repetition approach introduces also an extrinsic trigger to motivate the students to play the game. Therefore the aforementioned design principles do not apply completely here. While there should still be a well-designed combination of goals, feedback and rewards, there is still an algorithm in the background that determines the best time for a repetition of certain content (i.e. part of the game). This point in time is critical for the success of the spacing effect. When it has arrived, an alert informs the student that it is time to learn. This is basically an extrinsic trigger to play the game and to learn through it, not necessarily at that very moment but on that particular day. Another way to trigger an extrinsic motivation is the aforementioned reward-system. However, there might be a downside in this approach. According to Deci et al. (1999) rewards have the potential to undermine intrinsic motivation. Furthermore extrinsic motivation is highly focused on a certain outcome, like a reward, which is in contrast with intrinsic motivation, which is focused on the activity itself (Ryan & Deci 2000). Therefore, the reward-system should be sophistically designed in order to keep the focus on immersing the learning content. There are several ways to realize such a system, ranging from a simple, local score to a class- or even university-wide leaderboard. Since there are already several values used by the scheduling algorithms, scores for the reward-system can be derived from that. This way there is no need to keep a separate database for scores or a leaderboard. Since the learners are usually not aware of the way the spaced repetition algorithm works, they also don’t know about the used values to calculate the intervals. Therefore there should be a separate leaderboard which serves as a visual display for the reward-system towards the learners.

The time component is one of the hardest design problems which have to be solved with spaced repetition based mobile learning games. This affects the motivation on the one hand and the spacing effect on the other hand. We have already shown in another paper (Schimanke et al., 2013a) that learners tend to play a game several rounds in a row, especially when the game contains content which aims more at memorization and is less explorative and when the game is appealing to them. This leads to several repetitions of the same content in a short amount of time, which is contradictory to the spacing effect. This circumstance might therefore corrupt the spacing effect because the time between two repetitions of the same content might not be in line with the algorithm’s calculation for the next repetition. Therefore we have already introduced the FS-algorithm (Schimanke et al., 2013a) which takes over the repetition scheduling after the first round of play of each gamesession. Herewith we are able to keep the integrity of the values the SM2 algorithm uses for scheduling the next repetition according to the spaced repetition approach on the one hand, while avoiding back-to-back repetitions of the same content on the other hand.
However, when designing a learning game to keep the learners’ motivation for playing the game at a high level, the issue might become even bigger. While elements like rewards or a great gameplay are extrinsic motivators in the first place, they also have the power to convert this extrinsic motivation to intrinsic if they become meaningful to the learner (Deci 1999). Hence, when a learning game is designed so well that the learners get fascinated just by the gameplay, they might play even more rounds due to their intrinsic motivation, which leads to an even bigger negative effect on the repetition scheduling algorithms. That means that too much design for motivation can be counterproductive regarding the spacing effect. However, this does not mean that the design of a spaced repetition based learning game should be de-motivating. A proper design therefore needs to find a good balance between motivating the user while keeping the focus on the learning content and while ensuring that the intervals calculated by the algorithm are still followed. Learning games naturally have a certain amount of intrinsic motivation, as long as the learner wants to learn the respective content. Spaced repetition based learning games also add an extrinsic motivation to play the game by alerting the user when the time for a scheduled repetition has arrived. This raises the question whether it is important to place emphasis on good design in spaced repetition based learning games at all. There are several factors which influence the motivation, as can be seen in figure 3. At this point we have to distinguish between the motivation to play a learning game at a given time and the motivation to use it at all. While the motivation to launch the game and play it can be triggered externally by an alert on the device, the motivation to use the learning game at all is often influenced by its design. It should therefore be designed to be appealing to the learner while not focusing too much on “eye candy” to ensure that the focus is still on the content. Hence, when a game is well designed, this may lead to an intrinsic motivation for the learners to play it because they like it or because it is fun to play. Furthermore, there is no need to distinguish between an intrinsic motivation for learning or for playing because the learning takes place through the game each way.

The alert-function is also an important aspect when designing a mobile learning game that relies on the idea of spaced repetitions. Mobile learning games enable a student to learn almost anywhere and anytime. Using alerts to remind learners when it is time for learning (i.e. the next repetition) is almost a natural choice in this environment. They have the potential to ensure that the repetition is executed just at the perfect time as calculated by the repetition algorithm. This is not a matter of the right hour but more a matter of the right day. Alerts should therefore always be included in the design of spaced repetition based mobile learning games, optimally including an option for the learners to make the game alert them again later that day.

On a side-note a proper design for spaced-repetition-based mobile learning games also affects the way the content is categorized. When learning things like vocabulary using learning cards, the content is very atomic, which means that there are single words as learning content. However, in learning games there is often content in different tasks which is very similar to each other and which can therefore be combined in categories. We have already shown how this can be done (Schimanke et al., 2013b) and what considerations have to be made.
Blurring Learning Content

As indicated in our introduction, games by themselves are designed to be fun in the first place while learning is often seen in a more negative way. This should be taken into consideration when designing and using learning games, for example by blurring the learning content behind a fun and motivating gameplay, while ensuring that the focus is still on the content. Ideally this makes the learners learn without even knowing it, just by playing the game. On a downside this is often not completely possible for several learning topics. When using the learning games in blended learning scenarios, learners implicitly know that the game is intended to be used for learning and thus cannot simply blind this out. All the more it is important to blur the learning content within the game with real-world scenarios which makes it easier for the learner to understand the underlying concept and to apply it later on.

We have therefore designed a prototype mobile game for learning the concept of the Cartesian product which abandons the traditional presentation of tables and tuples and uses a metaphor from the real world instead. One example could be derived from a restaurant where they have a menu with several courses and different dishes for the courses. This scenario is presented like a real menu and gets combined with a special task, like for example “Assemble all combinations of vegetarian meals from the menu.” as conceptually depicted in figure 4. The learners then have to select the appropriate dishes from the courses to solve the task. This is simply done by dragging the respective dish from the menu to the desired spot in another table showing all user selections. By tapping on the selections, the learners are also able to remove the dishes from that table. When they are done, they tap on a “Done” button which finishes the task. Based on the given task and the selected dishes, our learning game then gives a feedback about whether the task was solved correctly or not. In the latter case, the game will also provide the learners with the correct solution.

Another example could be to present a wardrobe with different types of clothing and ask the learners to select the appropriate clothes for certain weather conditions in a similar way. Both ways the learners get presented with a familiar scenario from the real world which is at a first glance not directly connected to database concepts and thus supposedly helps them to understand it better than in a strictly theoretical way. The spaced repetition algorithm in the background adds to that by selecting the correct content at the respective time in order to achieve the best possible learning results.

The conflict between motivation and spaced repetition

As mentioned above, there is a field of conflict between too much intrinsic motivation to play the game and the spaced repetition approach. When the learners get lost in the game because it is too addictive and creates a high level of intrinsic motivation, they might play it at times that are not in line with the calculated spaced repetition intervals. One way to solve this conflict could be to present alerts to the learners when they have accomplished the scheduled tasks for this session and should stop playing the game. However, according
to good practices in game-design (Nielsen 1993) they should still be able to decide for themselves whether they want to play another round of the game or if the want to quit. Those alerts could then be designed in a way to motivate the users to finish the current round of play while also motivating them to return to the game not earlier than on the next scheduled point of time. This could be achieved by a reward-system which creates an extrinsic motivation to climb for example in a ranking or leaderboard, but which is also directly connected to the scheduling of the learning intervals. This way the learners can only climb in the ranking when playing the game at a scheduled repetition-time and only once (i.e. in the first round of play) at each usage of the game at that time.

In other words, when using spaced-repetition-based learning games, the reward system should be adapted in a way that it motivates the learners to use the app primarily at the calculated times. This can be accomplished by limiting the moments when rewards can be gained to just these times. In any case the game should let the learners know about this by informing them for example with alerts when they launch the game (Figure 5).

Another way to make the learners play the game only at calculated times can be derived from the motivational aspect of the game. While different techniques can be used to create some kind of motivation to play the game at certain times, those techniques may also be used to demotivate learners to play it at other times. This can be achieved for example by setting the level of difficulty too high or too low compared to the learners’ measured performance. However, this demotivational approach always involves the danger to demotivate the learner completely to play the game even at the calculated times. Therefore the approach with using the reward-system appears way more promising to make the learners play the game primarily at the optimal intervals.

Overall, spaced-repetition-based learning games should be designed in a way that they motivate learners to play mostly at the calculated times according to the spacing effect. This distinguishes classic learning games from spaced-repetition based learning games as can be seen in table 1.

<table>
<thead>
<tr>
<th>Classic Learning Game</th>
<th>Spaced-Repetition based Learning Game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic triggers make the learner play the game.</td>
<td>Extrinsic reminders make learners play the game at a calculated time.</td>
</tr>
<tr>
<td>Played at unspecified times.</td>
<td>Alerts remind learners to play the game when it is best according to the spacing effect.</td>
</tr>
<tr>
<td>Engage learners over a long period of time.</td>
<td>Keep learners in the game only for one round of the scheduled content.</td>
</tr>
<tr>
<td>Bloom’s taxonomy (Anderson revision): Apply, Analyze, Evaluate, Create</td>
<td>Bloom’s taxonomy (Anderson revision): Remember, Understand</td>
</tr>
<tr>
<td>Raise intrinsic motivation through extrinsic triggers like rewards, every time the learners reach a certain goal</td>
<td>Create motivation to play the game at given times by only rewarding learners when playing according to calculated intervals</td>
</tr>
</tbody>
</table>

Table 1: Comparison of design considerations for different kinds of learning games
Conclusion and Future Work

Spaced-repetition-based mobile learning games impose special requirements on the design. There is a huge area of conflict between designing an app with motivation in mind on the one hand and the spaced repetition approach on the other hand, though this depends heavily on the amount of content available within the game. While traditional design for fun games and for learning games likewise usually aims at keeping the player in the game for a long period of time by creating some kind of intrinsic motivation, this scenario can be counter-productive for spaced-repetition-algorithms. Especially when there is only limited content available in the game, chances that the learner plays several rounds of the game in a row are pretty high. In this case there has to be an auxiliary algorithm which keeps the integrity of the values used by the spaced-repetition-algorithm to calculate the intervals between two learning sessions with the same content. While learning games should always create an intrinsic motivation within the learners to play the game, spaced-repetition-based learning games also offer extrinsic motivations in terms of alerts which remind the learners to play the game at just the perfect time as calculated by the algorithm. This requires a special design-approach which takes into consideration the aspect of motivation as well as the idea behind spaced repetitions.

The system of goals and rewards offers a good way to guide the learners to play the game mostly at calculated times. Those goals and rewards are basically extrinsic triggers to motivate learners to play the game, for example by making them advance in rankings due to a good performance. However, in spaced-repetition-based mobile learning games the reward-system should be designed in a way that rewards should only be granted when the game is played at the calculated times.

Our findings provide a good groundwork for future work on this topic. One example would be to improve the auxiliary algorithm based on research about short-term memory and its impact on the retention if the learners play several rounds of the game in a row. This should then be taken into consideration in order to achieve an even better calculation of the next scheduled repetition as well as on the content selection.

At the current stage, the prototype apps alter the score for each category which is used by the algorithms as “quality of response” only by right or wrong answers and increments or decrements the value accordingly. At a future stage this altering should be done in a more sophisticated way in order to better reflect the actual learning performance of the users. One approach for this could be to analyze the time between the presentation of the content and the learners’ answer and then draw conclusions from that. This will also go hand in hand with the aforementioned research on the impact of playing several rounds in a row.

References


