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Author(s): Lämsä, Joni; Hämäläinen, Raija; Aro, Mikko; Koskimaa, Raine; Äyrämö, Sanna-Mari

Title: Games for enhancing basic reading and maths skills : A systematic review of educational game design in supporting learning by people with learning disabilities

Year: 2018

Version: Accepted version (Final draft)

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Please cite the original version:

Lämsä, J., Hämäläinen, R., Aro, M., Koskimaa, R., & Äyrämö, S.-M. (2018). Games for enhancing basic reading and maths skills : A systematic review of educational game design in supporting learning by people with learning disabilities. *British Journal of Educational Technology*, 49(4), 596-607. <https://doi.org/10.1111/bjet.12639>

Games for enhancing basic reading and maths skills: A systematic review of educational game design in supporting learning by people with learning disabilities

Joni Lämsä^{a*}, Raija Hämäläinen^a, Mikko Aro^a, Raine Koskimaa^b and Sanna-Mari Äyrämö^b

^aDepartment of Education, University of Jyväskylä, Jyväskylä, Finland; ^bDepartment of Music, Art and Culture Studies, University of Jyväskylä, Jyväskylä, Finland

Joni Lämsä

Department of Education, University of Jyväskylä

tel: +358 40 8054271

e-mail: joni.lamsa@jyu.fi

Mr Joni Lämsä is a Ph.D. student at the Faculty of Education and Psychology, University of Jyväskylä, Finland. His research interests include collaborative learning in technology-enhanced contexts.

PhD Raija Hämäläinen works as a full Professor at the University of Jyväskylä. Her main research interest deal with technology-enhanced learning. Raija is the associate editor in Educational Research Review (2018–2022).

PhD Mikko Aro is a professor of Special Education at University of Jyväskylä. His primary research interests relate to development of literacy and mathematical skills; dyslexia, dyscalculia and their comorbidity; and interventions of developmental reading and arithmetic disabilities.

PhD Raine Koskimaa is a Professor of Contemporary Culture Studies at the University of Jyväskylä, and the Vice Director of the Finnish Center of Excellence in Game Culture Studies. Koskimaa is the editor-in-chief in the Finnish *Yearbook of Game Studies*.

Sanna-Mari Äyrämö is a Doctor of Philosophy in Digital Culture. Her interests include new digital games.

Abstract

The development of games for people with learning disabilities is one way to enhance the quality of learning and respond to the need for inclusive special educational support. Recently, game researchers have highlighted the need for paying more attention to identifying the game design choices that can strengthen learning. This article reviews recent studies in the field of games that aim at supporting people with difficulties in learning, particularly in basic reading and maths skills. We identify the major characteristics and learning outcomes of the reviewed studies, as well as key design principles that have been used in games for enhancing basic reading and maths skills. The results show that people with specific learning difficulties have positive improvements in the quality of learning. We also found specific gamification elements that have been used to promote the learning of basic reading and maths skills. However, we call for research, which would explicitly examine the effects of game design choices on learning. Currently, the studies that address learning disabilities do not specifically define which kind of games and game design the results refer to, while game design studies do not clarify how these games influence learning. Thus, there is a need to rethink previous empirical studies on game settings for people with learning difficulties via advancing the role of game design in empirical intervention studies.

Keywords: dyscalculia, dyslexia, game design, games, learning disability

Introduction

There is a great deal of optimism surrounding the potential of games in supporting learning by people with learning disabilities. In the area of basic reading and maths skills, games have the potential to enhance children's engagement with literacy and maths activities, foster skill reinforcement and empower learners' perceptions of their reading progress (Koskimaa & Fenyesi, 2015). Learning has cognitive, social and emotional dimensions in which players engage. The central challenges of game-based learning relate to getting children with learning disabilities excited about learning in game settings, maintaining their motivation to practice a skill that has been proven difficult to grasp and mastering a skill that requires considerable repetition. However, motivation is often considered self-evident in any game-like application. Some game researchers have even proposed that learning games may be poorly designed, and that game developers have little understanding of how to design these types of games (e.g., Haworth & Sedig, 2011). Thus, from the perspective of game design, there is a need to identify the mechanisms of a learning game design to strengthen the game features (e.g., good games are cohesive, are varied and have good user interaction; Äyrämö, 2017). We argue that utilising games to support learning by people with learning disabilities is a challenging process that should consider two perspectives: game design and learning disabilities. The current article draws on these two areas, seeking to bridge the gap between them and advance learning game development and research on learning disabilities. Next, we briefly define the framework of learning game studies and research on learning disabilities.

Educational Games

To understand how to design learning games, it is important to first define the term game, of which there is no universally accepted definition. We build on Juul's (2005) 'classic game model', which defines a game as 'a rule-based system with a variable outcome, where different outcomes are assigned different values, the player exerts effort to influence the outcome, the player feels emotionally attached to the outcome, and the consequences of the activity are negotiable'. Salen and Zimmerman (2004) reached a bit more condensed formulation, defining games as systems in which players engage in an artificial conflict and whose actions are defined by rules, all of which results in a quantifiable outcome. The socio-cultural theory of games emphasises that games are situated within game-playing communities, and the theory 'focuses on learning as participation in social practice' (Ramirez & Squire 2015).

Qualities attached to non-educational games are not sufficient on their own to make the games educational. Educational games are often seen as a subcategory of serious games (Hailey, Connolly, Stansfield, & Boyle, 2011), which, according to Zyda (2005), are mental contests played with a computer that use 'entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives'. Instead of educational games as such, researchers' interest increasingly has been on game-based learning and gamification of learning. Gamification refers to the practice of applying game elements or functionalities such as points, rewards, tasks, challenges, goals or immediate feedback for learning purposes. Gamification aims at fostering playful and gameful attitudes, which are considered beneficial for learning. Suits (1990) wrote about the player's lusory attitude that makes the player accept the artificial rules and obstacles of a game and see them as enhancing

the game's fun, rather than merely being nuisances. Mäyrä (2012) identified free play, creative fun and non-instrumental leisure as the characteristics embodied in playfulness.

Educational games are increasingly used to support learning by people with learning difficulties (e.g., for supporting job training of persons with developmental disabilities; Kwon & Lee, 2016). Game designers should take pedagogical principles and elements regarding accessibility into account so that disabled students are also able to achieve the desired learning outcomes (Hersh & Leporini, 2013). Hersh and Leporini (2012) argued that game categorisations (e.g., alternate reality games, simulations/microworlds, and role-playing games) link the diverse types of games to the type of learning they support. Furthermore, according to Bedwell and colleagues (2012), the game's characteristics that are relevant to learning can be classified into the following categories: 1) action language, 2) assessment, 3) conflict/challenge, 4) control, 5) environment, 6) game fiction, 7), human interaction, 8) immersion and 9) rules/goals. We also must consider that not all educational applications are called 'games' by their developers; one reason for not identifying something as a game is to avoid competition with commercial games. However, it is not the aim of the current article to dwell on the demarcations of what qualifies a game, and our materials include both products called games and platforms with explicit gamified quantities.

Learning Disabilities

The major challenges of a child's first years of school relate to the acquisition of accurate and fluent mastery of written language, as well as basic calculation skills. Specific learning disabilities in literacy or arithmetic are the most common and extensively studied learning difficulties (e.g., Galuschka, Ise, Krick, & Schulte-Körne, 2014). From the point of view of supporting learners who are struggling with the mastery of these basic academic skills, educational games can have several benefits. First, games can support a student's motivation for practicing the compromised skill for extended periods, which is usually required in the case of learning difficulties (Hersh, 2014). Second, the adaptation logic of the games can help tailor the practice of the subskill and skill level, making it the most beneficial for each individual learner's stage of development (Saine, Lerkkanen, Ahonen, Tolvanen & Lyytinen, 2011). Third, games can provide immediate, supportive and corrective feedback of their performance, which has been shown to be an important element of educational interventions (Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009). Finally, game-based learning can also be cost-effective, here reducing the need for teacher involvement during the practice of skills.

Dyslexia and dyscalculia are the most common reading and maths disabilities. Estimated prevalence rates of both developmental learning difficulties vary between 4–9% for dyslexia and 3–7% for dyscalculia (Landerl & Moll, 2010). Both learning disabilities are also associated with generally low educational outcomes and have been the focus of research aimed at gaining a better understanding of the cognitive underpinnings of these problems. Lyon and colleagues (2003) summarised developmental dyslexia as a specific learning disability characterised by difficulties in accurate and/or fluent word recognition and spelling and decoding problems. These difficulties are generally thought to result from a deficit in processing language at the phonological level. Although dyslexic readers often have problems with reading comprehension as well, their difficulties are considered as resulting from problems with word recognition. Thus, the most successful approaches for supporting learners with dyslexia have focused on language skills — more specifically on phonological processing, decoding and

word recognition skills. Dyscalculia refers to a deficit in one or many content areas of mathematics. As Furlong and colleagues (2016) pointed out, most research thus far has focused on early problems in achieving basic mathematical skills, such as arithmetic reasoning (addition, subtraction, multiplication and division) or number-specific precursor skills ('number sense'), for example, estimating quantities, understanding counting and transcoding between number words, digits and quantities. However, the nature of dyscalculia is multifaceted, which has been a challenge for practitioners attempting to develop interventions (Dowker, 2005).

We focus on games meant for enhancing basic reading and maths skills: we also take into consideration digital learning games that comply with the formal definitions of a game (player, conflict, rules and quantifiable outcome), as well as digital learning platforms and applications that have explicit gamified qualities. First, we investigate the major characteristic and learning outcomes of the studies in which the aim of the game is to enhance basic reading and maths skills. Second, we identify the key design principles that have been implemented in the game design. Finally, we evaluate the beneficial gamification elements that can support learning by people with learning disabilities. The following three research questions (RQ) are addressed:

RQ 1: What are the major characteristics and learning outcomes of the studies on serious games for enhancing basic reading and maths skills?

RQ 2: What kinds of key design principles can be identified in research that uses games for enhancing basic reading and maths skills?

RQ 3: What kind of gamification elements are used to promote learning by people with learning difficulties?

Method and materials

We started by conducting a systematic review in which we searched the articles focusing on games for enhancing basic reading and maths skills. After that, we analysed the selected articles in three phases.

Search protocol

Our search protocol is based on recommendations from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group, 2010). We applied the following four phases: identification, screening, eligibility and inclusion. An overview of the search protocol is presented in Figure 1 in which we present the number of studies and the inclusion criteria in each phase. We elaborate our search protocol in Table S1.

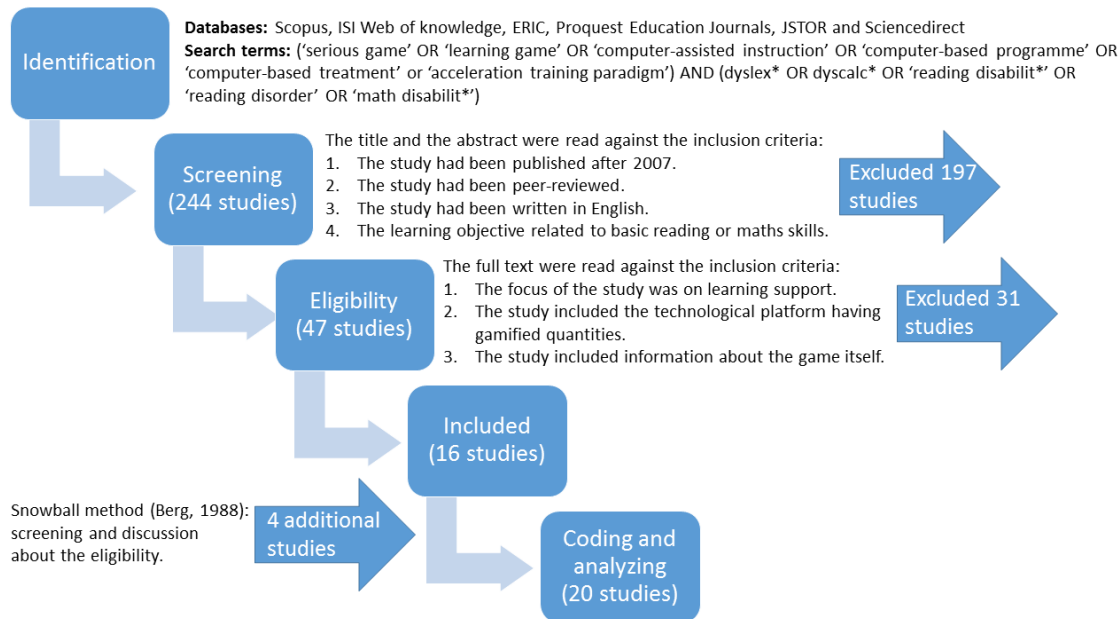


Figure 1. An overview of the search protocol: the number of studies and the inclusion criteria in each phase.

Data analysis

We developed a coding scheme to systematically analyse the studies. The articles were coded and analysed by the study's authors. Our coding was done in three phases so that we could identify the (1) main characteristics and learning outcomes of the studies (RQ1), (2) key design principles of the games (RQ2) and (3) the gamification elements that refer to being beneficial for learning (RQ3). First, we focused on the main characteristics and the main learning outcomes of the studies of serious games and how they could enhance basic reading and maths skills. This coding included 1) whether the game focuses on reading or maths performance, 2) the number and age of participants, 3) the descriptions of control groups, 4) the form of pre- and post-tests, 5) the length of the gamified interventions/periods and 6) the learning outcomes. In the second phase, we adopted a set of variables (Järvelä, Ekman, Kivikangas, & Ravaja, 2014) to classify different types of games: to identify the key game design principles of the selected studies. As a result, we looked at six gamification elements of the educational games found by our review: 1) what is the context and fantasy of the game, 2) whether the game is played individually or collaboratively, 3) whether the playing is occasional or long term basis, 4) whether the game is adjustable and customisable, 5) whether the game utilises audio-visual aspects and 6) whether the game is adaptable. We also looked at four other properties: 7) whether the game is a learning or entertainment game, 8) whether the task type is cognitive or kinetic, 9) how the game's achievements relate to learning and 10) how the game utilises log data. Additionally, we focused on the role of teachers during gamified activities.

In the third phase, our aim was to evaluate what kind of gamification elements are beneficial in the context of supporting learning by people with particular learning difficulties. We conducted a thematic content analysis (Braun & Clarke, 2006) of the 20 empirical articles. In analysing the 20 research articles, we followed Aveyard's (2010) idea of evaluating the differences and similarities in the different papers rather than simply summarising them. The

aim was to evaluate studies from the perspective of game design and learning outcomes. In this phase, we excluded the articles that focused on piloting the game or conducting a study without learning outcomes. In total, we found seven studies (and seven different games) (underlined in Tables S2 and S3) with scientific evidence regarding the learning effects. We grounded our thematic analysis on the six gamification elements identified in the second phase (labelled as 1–6 also in Table S3). We evaluated if and how the studies used these elements to enhance learning. Finally, five authors engaged in a process of critical discussion of the evaluation patterns.

Results

The major characteristics and the main learning outcomes of the studies

The summary of the major characteristics of the reviewed studies and their measured learning outcomes are presented in Table S2. Most of the studies (14 articles) focused on games and reading disabilities (17 different games) while six presented a game with the aim of enhancing calculation skills (five different games). Most of the studies were small scale: 11 studies had less than 50 participants, three had between 50 and 100, and only two studies had 100–200 participants. Three of the studies did not report the number of participants and one study did not specify participant characteristics. Overall, 657 participants were included in the 20 papers, from which 12 of the studies were journals, five conferences and three book articles. The participants were 4–12-year-old children.

In the reviewed studies, the aim of the games was to improve either the accuracy or speed of reading or calculation performance, or in the case of more targeted goals of practice, the respective subskills of performance. For example, Saine et al. (2011) found that playing GraphoGame had a positive influence on reading accuracy and fluency, as well as letter knowledge and spelling; a study on NumberRace (e.g., Wilson, Dehaene, Dubois, & Fayol, 2009) reported encouraging results of basic mathematical skills achievement. To evaluate the effects of these games, however, attention should be paid to their experimental designs. As shown in Table S2, the most popular research design consisted of pre- and immediate post-tests ($n = 10$) with a control group ($n = 7$). The control groups comprised both children with learning disabilities ($n = 4$, e.g., de Castro Bissaco, Panccioni, Rodrigues, & Domingues, 2014) and children without the need of extra support for early number or reading skills ($n = 3$, e.g., Salminen, Koponen, Räsänen, & Aro, 2015). The features of the control group, such as the correspondence to the experimental group and the support offered for the control group, are relevant for making conclusions concerning the effects of the game (Mohd Syah, Hamzaid, Murphy, & Lim, 2016). The length of the intervention studies varied from 1 to 28 weeks.

Four intervention studies (e.g., Salminen et al., 2015) in learning-oriented publication channels reported the effect sizes of the learning outcomes (see Table S2). In addition to statistical significance, the effect sizes revealed the practical relevance of the findings. As already reported by Räsänen et al. (2009), a comparison of effect sizes is challenging because they are calculated both by comparing the differences between groups ($n = 3$, e.g., computer-assisted intervention group vs. mainstream learners) and by comparing the differences within intervention groups ($n = 1$). Only Torgesen and colleagues (2010) followed up the study with a post-intervention to evaluate the stability of the positive effects observed. Instead of effect sizes, the game design studies (e.g., Wilson et al., 2009) typically reported whether there was a statistically significant difference between the pre- and post-test results ($n = 6$). Three of these

studies (e.g., de Castro et al., 2014) did not report an interaction effect; they only compared pre- and post-test results separately for the experimental and control groups. Altogether, five studies (and five different games) reported at least some improvements in reading skills. Similarly, improvements in mathematical skills were found in five studies (four different games).

In addition to intervention studies, Vasalou and colleagues (2017) conducted a qualitative study and reported the results of a thematic analysis on children's verbal and non-verbal interactions during gamified activities. Finally, we found two studies reporting the preliminary findings of piloting a game and six studies that described the design and development processes of a game (see Table S2). The results regarding LexyLink were discovered in a study that did not fulfil our inclusion criteria (a more than 10-year-old study).

Key design principles of the games that enhance basic reading and maths skills

The general feature of the studies described above is that they validate the use of a game. However, despite this advantage, it is still difficult to pinpoint which design principles are influential for increasing students' learning (see also Wilson et al., 2009). In Table S3, we illustrate the key design principles of the games that can be identified in the research on games for enhancing basic reading and maths skills. Furthermore, our evaluation sought indications on how game design is associated with learning. In the following subsection, we analyse further how gamification elements (context and fantasy; individual or collaborative playing; occasional or long-term playing; adjustability and customisability; audio-visual aspects; and adaptability; see Table S3) were used in the selected studies (underlined in Table S2). However, it should be noted that the gamification elements were not an explicit focus of these studies; rather, they were implicit indications.

From a game design perspective, all the games were learning games, and almost all the games in our materials shared some qualities (see Table S3). In all the 22 games listed in Table S3 (reported in 20 articles), the task type was cognitive (with some kinaesthetic challenges), which is understandable because these games are meant to help children with cognitive disabilities. The games were intended to be played occasionally so that the games were easy to learn in short sessions. In all the studies, a common idea was that gamification supplemented teacher instruction, and the role of the teacher was not essential during gamified activities because most of the studies ($n = 14$) mentioned nothing about it. Some of the games include time limits (e.g., Hamilton, 2016), which may pose kinaesthetic challenges in that the player must physically react within the given time frame, but there is no additional spatial precision requirement (e.g., it is sufficient to click on a mouse key, no matter where the cursor is located, or the area to click is relatively large). All the games were played individually, but de Castro et al. (2014) illustrated that it is possible to add social functions to single-player games, such as chatting. As shown in Table S3, more than a third of the cases did not take advantage of adjustability or adaptability. Most cases employed audio-visual content, but in some cases, the games only had audio or graphics but in a modest way. Almost all the cases provided some sort of fictional world where the tasks take place (e.g., Vasalou et al., 2017), and often, the world included characters (e.g., de Castro et al., 2014). The game world was mainly nature oriented with animal characters.

Evaluation of beneficial gamification elements in supporting learning by people with learning disabilities

Our evaluation aimed to determine whether and, if so, how the specific gamification elements (see Table S3) were used in the empirical studies (underlined in Table S2). Content-based adaptation and feedback systems (indicated by Räsänen et al., 2009; Saine et al., 2011; Salminen et al., 2015; Torgesen et al., 2010; Wilson et al., 2009) were mentioned as the key features of game design. For instance, Räsänen et al. (2009) and Salminen et al. (2015) focused on comparing the effect of two different games (GraphoGame-Math and Number Race) with students' number skills performance. These studies compared the effect of different dyscalculia-oriented elements (the importance of the exact magnitudes and number symbols vs. approximate comparison processes). However, in both games, adaptation was used to increase variation in the practised context. Content-based adaptation in learning games is often seen as a way to adapt the challenge to an ideal level (to maintain the flow), and it is one key feature of game design that is beneficial for learning purposes (e.g., Salen & Zimmerman, 2004). Salminen et al. (2015) also indicated that a time pressure was used to trigger playing. In game design, challenges may require time-critical or time-independent performance (Karhulahti, 2013). Time-critical performance is often conducted in haste (Elverdam & Aarseth, 2007), and it puts a greater emphasis on motoric skills and reaction times. As in the educational games discussed here, the main task is a mental one, not kinaesthetic, so it is important to adjust the temporal pressure in such a way that the possible limitations in the student's motoric skills are not interfering with performance. Adaptation and an individualised feedback system can also be seen as favouring the individual learning of children with learning disabilities (e.g., Salminen et al., 2015) because dyslexia and dyscalculia often require individually tailored interventions.

When designing the context, fantasy and audio-visual aspects of the games, an essential viewpoint is to engage children in the gameplay. Mohd Syah et al. (2016), Torgesen et al. (2010) and de Castro et al. (2014) highlighted that colourful settings and fun characters (mentioned also by Salminen et al., 2015), possibly along with audio-visual effects, may be engaging elements. A scoring system (Mohd Syah et al., 2016) and immediate feedback (Saine et al., 2011) were also mentioned as engaging and motivating features of the games. Scoring and feedback are an integral part of game design (Schwartz & Bayliss, 2011). This kind of engagement is important because usually, engagement is specifically what is sought through gamification. On the other hand, there are different dimensions to engagement: behavioural, cognitive and emotional (Ge & Ifenthaler, 2017). Emotional engagement alone without consequent cognitive engagement does not necessarily contribute to learning. Immediate feedback is important in articulating how the elements being manipulated should be directly relevant for the skill being learned. Fun-increasing elements, on the other hand, do not seem to have a direct connection to learning success (Iten & Petko, 2016). None of the studied games required long-term playing; the learning effects were achieved by engaging in occasional, recurrent playing.

We also evaluated how adjustability has been used to promote learning. Even though all the selected studies, save for Torgesen et al. (2010), indicated that the games were adjustable, their role in learning performance was not analysed or considered. If learners selected which skills they would practice and at what level, the teacher's role should be to map the learning feedback with game achievements so that the game teaches the right lessons to its player. In the current

review, it was not easy to detect the extent to which this was accomplished, but it seemed to be the case in roughly half of the studies.

Discussion

Several game-like tools exist (see Figure 1), and the advantages of games as potential tools for supporting learning by people with learning disabilities are generally supported. However, the current research seems to be divided between studies focusing on supporting learning by people with learning disabilities and studies describing the design of game-based technological applications, and there is little discussion between these two approaches. On the one hand, the articles originating from the tradition of gaming define the game content and report learners' experiences of the game environments in detail, here only marginally focusing on either the learning outcomes or theoretical basis of the application. On the other hand, the reports more focused on the learning disability describe, often marginally, the specifics of the game design and mechanics, focusing instead on the learning processes or subskills that are supposedly practised in the game, as well as the practical outcomes from the point of view of the compromised skill.

In game design studies, several advances for learning were found (e.g., positive experiences, as indicated by Gaggi et al., 2017), and 10 of the studies showed the positive effects on cognitive skills (see Table S2). However, the social and emotional dimensions of learning seem to be lacking. Thus, our recommendation for the use of educational games to support learning by people with learning disabilities is that future games should better utilise the social and emotional dimensions of learning. Currently, it seems that the games may not yet optimally match the needs of twenty-first-century learning environments, such as learning approaches that focus on social forms of learning (Kafai et al., 2017) or have a high enough level of technological development. Our concern is that if the gap between learning games and other games grows too wide, learning games may suffer because students with disabilities participate routinely in a wide variety of entertaining and engaging games, making the learning games less appealing. Optimally, games supporting learning by people with learning disabilities should be just as motivating as these non-educational technological contexts, with the added value that players will learn.

Next, we will further discuss and provide recommendations for how the design principles and game design reflected in the current study could be better employed in learning games. First, currently, the studied games did not take full advantage of adjustability and adaptability. However, both adjustability (the possibility for the user to modify the appearance or some of the functionalities of the game) and adaptability (the game monitoring user performance¹ to maintain the ideal level of challenge) are well-developed aspects in game design. For the future, we recommend using these aspects to address the need for individual tailoring. Second, our recommendation is that future applications support both adaptability for individual needs and social functions (only one of the reviewed studies took advantage of technology-mediated collaboration) in the same game context should be used to bring together two important aspects of inclusive education. Social aspects of game play could be used to heighten the sense of

¹ If user-tracking data are transferred, collected or forwarded from a personal device to an external server for research or whatever purposes, ethical concerns may arise. The normal requirements concerning personal data security and informed consent apply in this case. Typically, however, quantitative and big data approaches are employed on such data, and all data is anonymised and there is no connection to any individual user.

achievement by enabling easy sharing of play sessions or specific stages. Educational games could apply social functions, such as what is done in the game Monument Valley, an entertainment game with educational potential in geometry and proof construction and that includes a one-click option to share screenshots of the beautiful, and often surprising, imagery (Koskimaa & Fenyvesi, 2015). Third, occasional play sessions may often be practical (cf. Peirce & Wade, 2011) but not necessarily optimal for maintaining cognitive engagement for longer periods ('light-attention mode of engagement', Hinton & Hjorth, 2013), which is often needed because skill improvement for people with learning disabilities usually takes effort over an extended period of time. For example, Ronimus, Kujala, Tolvanen, and Lyytinen (2014) indicated that although novel tasks and fantasy elements in games may increase disabled children's engagement in learning games, this effect may not be long-lasting if there are shortcomings in the game design. Games with longer storylines or wider fictional worlds, on the other hand, are impractical in that reaching a specific point may require a long sequence of events. To better meet the need for engagement, we recommend combining the flexibility of casual games and longer interest factor of bigger games, for example, by making a series of casual games, as employed in the studies of Gaggi et al. (2017) (see also Smith & Sanchez, 2010).

Our final recommendation concerns future empirical studies on game settings for people with learning difficulties. Namely, our evaluation of the studies illuminated that the game-specific parameters related to, for example, stimulus presentation, adaptation algorithms or game mechanics, were not the explicit focus of the studies. Rather, the parameters seem to be fixed elements of the game. The unanswered question is what kind of role these properties play in students' learning and gaming experiences and what kind of parameters best enhance students' reading and maths performance. Therefore, we call for empirical intervention studies based on the given design guidelines and recommendations (see e.g., Hersh & Leporini, 2013) that would separately investigate the effect of gamification elements and/or design principles on the one hand and the effect of learning-disability-oriented properties in game design on the other (see e.g. Mohd Syah et al., 2016). This would enable the development of a research-based framework for designing or evaluating educational games that support learning by people with learning disabilities (cf. Hersh, 2014).

Conclusion

The current review illustrates that along with the development of gaming technologies, game design has become a topical issue in terms of enhancing basic reading and maths skills. The present study illustrates that to develop the field further, serious attempts should be made to integrate the knowledge of learning disabilities and experimental intervention methodologies with explicit knowledge on gaming research (see also Hersh, 2014). There is a need to rethink the previous empirical studies on game settings for people with learning difficulties (see e.g. Hwang & Wu, 2012) through advancing the element that has thus far been lacking: the role of game design. With this type of integrative approach, one would not only be able to develop better and more efficient gaming applications for people with specific learning disabilities, but also better understand the effects of gaming parameters from the perspective of motivation and engagement in general.

Acknowledgements

This research was supported by the Academy of Finland (Project 258659, Project 276012, Project 277340) and the Finnish Cultural Foundation.

Statements on open data, ethics and conflict of interest

The research ethics guidelines of the Finnish Advisory Board on Research Integrity (2012) were followed throughout this study. Data collection, analysis and publishing followed the modes of action endorsed by the research community: integrity, meticulousness and accuracy in conducting research. The review data are available to others. There is no conflict of interest.

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