Motivational potential of leaderboards in a team-based math game competition

Manuel Ninaus[1,2,3] [0000-0002-4664-8430], Sara de Freitas[4], and Kristian Kiili [5]

[1] Department of Psychology, University of Innsbruck, Innsbruck, Austria
[2] LEAD Graduate School and Research Network, University of Tübingen, Tübingen, Germany
[3] Leibniz-Institut für Wissensmedien, Tübingen, Germany
manuel.ninaus@uibk.ac.at
[4] Department of Computer Science and Information Systems, Birkbeck University of London, London, United Kingdom
sara@dcs.bbk.ac.uk
[5] Tampere University, Tampere, Finland
kristian.kiili@tuni.fi

Abstract. Leaderboards are a popular way to implement competition, trigger social comparison, increase participation, and provide goals and performance-based feedback to the players. Even though game-based learning has become more common in education, relatively little is known about the motivational power of leaderboards in team-based educational settings. This paper aims to contribute to this gap by exploring to what extent leaderboards motivate players in collaborative and competitive game-based learning context. The meaning of leaderboards was studied in a team-based math game competition relying on intra-classroom collaboration and inter-classroom competition. The findings suggest that the team rank, team commitment, and enjoyment of the game predicted leaderboard motivation. The results revealed that even though leaderboards were motivating in general, players whose team did not succeed well in the competition were less motivated. It seems that leaderboards may facilitated collaboration but the collaborative element of the competition did not totally reduce the negative effects of the used infinite leaderboard. These findings disclose some drawbacks of an infinite leaderboard design. To overcome this problem, we suggest some ways to redesign leaderboards for educational use. Finally, we discuss implications of the research for using leaderboards in game-based learning settings, factors affecting leaderboard motivation, and leaderboard design in general.

Keywords: leaderboards, game-based learning, mathematics, team competition, collaboration.

1 Introduction

Game-based learning and gamification of learning is utilized to motivate learners by using game elements to enhance learners' interest and engagement in learning content [1]. Several meta-analyses have provided evidence that digital game-based learning can produce better learning outcomes than conventional learning approaches [2–4], but the subject domain as well as study design can remarkably influence the outcomes [3]. Accordingly, a meta-analysis of game-based mathematics learning reported statistically significant learning effects, however, the overall effect size was rather small [5]. Although several studies have indicated that game-based learning engages learners more than conventional instructional methods, the results of a meta-analyses by [3] did not support this common belief. The quality of digital game-based learning solutions tends to vary a lot that may partly explain these mixed results. Recent research has suggested that the effectiveness of different game features such as feedback, adaptivity, collaboration, competition, etc. should be more exhaustively studied with respect to learning and motivation [6]. This study contributes to this open question by exploring the motivational power of leaderboards included in a team-based math game competition.

1.1 Background

Competition is a common game element in which players compete with one another or with the game system. Previous results on the usefulness of competitive elements in game-based learning are mixed. Some studies have shown that competition can enhance engagement and playing performance (e.g., [7, 8]). For example, [7] found that leaderboards in a game enhanced students' motivation and performance. On the other hand, the competitive game element did not have such a positive effect in several other studies (e.g., [9, 10]). Competitive elements have been reported to result even in detrimental effects on learning outcomes (e.g. [11]). For instance, [11] found that competitive play in a math game resulted in the dominance of high achievers, which, in turn, decreased participation of low achievers. Furthermore, the study revealed that competition negatively affected collaborative learning for below-average students and positively for above-average students. A recent meta-analysis further revealed that competition in digital game-based learning was effective for math, science, and language, but not for social science and other subjects [12]. In general, the previous research has shown that competition is a multifaceted phenomenon, and the implementation, as well as contextual factors of the competition, can influence learning and motivational outcomes.

The use of a leaderboard is one popular way to implement competition, which seems to offer several advantages in game-based learning environments [13]. For instance, leaderboards may increase participation, provide specific goals for the learner, and provide means to evaluate learning progress. Accordingly, leaderboards provide feedback to the learner on their performance. Even though feedback has consistently been shown to positively affect students [14], it has also been demonstrated that the position in leaderboards affects its impact [15]. In particular, learners' reaction to receiving rather negative feedback (i.e. their performance is below a standard or below many other learners) can vary. Learners could increase their effort, reject the provided feedback or even abandon the activity (e.g., [15, 16]).

Leaderboards are also one of the simplest forms to facilitate social interaction (e.g., [15, 17]). In context of the self-determination theory, both collaboration and competition are factors addressing relatedness as well as the feeling of competence [18]. Enabling collaboration allows learners, for instance, to compete in teams to master challenges rather than overcoming them alone. Importantly, according to a recent meta-analysis on the effects of gamification competition combined with collaboration rather than competition alone seems to be particularly effective for improving behavioural learning outcomes as well as motivation [2]. Accordingly, the authors argued that competition alone might be suboptimal for at least some learners under certain circumstances. Utilizing a combination of collaboration and competition might help to reduce negative effects of leaderboards. Importantly though, collaboration can take many forms and to harness the potential of collaboration the task should require team members to share a common team goal and the success of reaching this goal should depend on all members of the group (e.g., [19, 20]).

Besides these reported specific effects of leaderboards, general learning related constructs such as learners' self-efficacy or the feeling of competence, respectively, and learning domain specific anxiety (e.g., math anxiety) have been considered as crucial factors in educational settings (e.g., [21]). In the domain of mathematics learning, it has been repeatedly demonstrated that low self-efficacy and high math anxiety negatively affects performance and motivation in traditional learning scenarios (e.g., [22–25]).

1.2 Present study

In the present study, we applied the 'Teams-Game-Tournament' (TGT) model [11]. The TGT model is one of the most well-known competitive collaborative models in which students both collaborate in teams as well as play individually to compete as a team against other teams. In particular, we organized a math game competition in Finland to support rational number instruction. The game utilized the so-called number line estimation task [26], which is an established way to assess and train students number magnitude understanding (e.g., [27–29]). In this task, students have to estimate the position of a target number (e.g. 1/4) on a horizontal line with only its endpoints specified (e.g. where goes 1/4 on a number line ranging from 0 to 1). Students were organized in teams or classes, respectively, and competed across the country in a math game. Students' (team) scores and the respective rankings were shown on a dedicated competition webpage and in the game. Accordingly, the design of the math game competition aimed at facilitating inter-classroom competition as well as intra-classroom collaboration. The overall objective of the current study was to exploratively examine factors that contribute to the motivational potential of the provided leaderboards. In particular, we were interested to investigate whether the rank of the team affects the perceived motivation of the leaderboard, as it is the case for individual competition settings (e.g., [15]). Motivation experienced by the provided leaderboards might also depend on the commitment (e.g., [8, 19, 20]). Besides that, we examined whether motivation is also driven by the overall enjoyment with the game as well as other more general learning related constructs such as math anxiety and self-efficacy (e.g., [21–25]).

2 Methods

We organized a nation-wide game competition in which we utilized a mathematics game designed to foster rational number knowledge. The competition for elementary school students, allowed students from Finland to climb the ladders of online team-based and individual leaderboards to rehearse and improve their mathematics skills. The current study is part of a larger project investigating the use of math game competitions to support rational number instruction. Using the same sample but different research questions and partly different variables, a previous study explored the educational potential of the math game competition and demonstrated that students increased their performance over the course of the competition (see [30]). The current study, focused on the motivational potential of the competition and leaderboards, respectively.

2.1 Participants

The competition was open for all Finnish 3-6 graders. Approximately 1,500 students from 35 different municipalities around Finland participated in the game competition. Participation was voluntary but students needed approval from their parents. From these 1,500 students 271 students (mean age = 11.62 years; SD = 1.03 years) filled in a questionnaire about the game competition and thus were considered for analyses in the current study. Of these 271 participants 116 were females and 155 were males. The median of self-reported mathematics grade was 9. In the Finnish classification scheme, 10 reflects the best and 4 the lowest grade. Most of the participants were experienced players as 62% of the participants reported that they play digital games at least a couple of times per week and 78% of the participants reported that they usually do well or extremely well in digital games.

2.2 Description of the game-based math competition

The competition was based on the Semideus game [28] which utilizes number line estimation task mechanics and it was organised around one randomized game level that can be completed in a couple of minutes. In each task participants had to estimate the position of a target rational number (fraction or decimal) on a number line (see Fig. 1). The tasks could include visual hints, mathematical traps, enemies, and player-activatable in-game skills that reduced the task demands (see details in [30]). The educational goal of the game was to foster students' rational number knowledge. To support social interaction, each participating class formed a team that competed against other classes. Furthermore, municipalities competed with each other. The web page of the competition included leaderboards for both teams and municipalities. We used the classic infinite leaderboard design in which positions are presented as an ordered ranking. Additionally, students could check their individual and team high scores and rankings through the game. Thus, the design of the competition included inter-classroom competition as well as intra-classroom cooperation to facilitate social interaction, which might counteract potential negative side effects of competition within a classroom.

Participants received feedback on their personal performance in several ways. The success of each task of the game was immediately communicated through points. More accurate estimates yielded more points. Moreover, after every estimation the correct location was shown by a green marker on the number line and in case of successful estimation (accuracy >= 92 %) the respective accuracy percentage was shown. For inaccurate estimates (i.e., estimates more than ±8% away from the correct location) the avatar was struck by lightning and the player lost virtual energy. The points earned in the level formed an individual high score. Number line estimation accuracy formed 70% of the level score and 30% of the score was given by remaining energy (energy bonus) when player completed the level. The player could lose energy by inaccurate estimates, stepping on traps (locations shown with rational numbers) and being hit by enemies. That is, the game score reflected player's conceptual understanding of rational numbers quite well and thus provided clear feedback about player's skill-level (maximum score was 100 points). After completing a level, the player received additional feedback via a star rating system: one star for completing the level, one star for collecting enough points, and one star for completing the level within the set energy loss limit. On the other hand, leaderboards were used to provide feedback on a team level. The team rankings were based on the average value of each team member's highest game score. That is, every member of the team contributed to the team score/ranking.

Fig. 1. The player had to estimate the position of the target number 3/4 on a number line from 0-1. In this particular instance, the player activated the in-game bird skill that divided the number line into four equal sized parts.

2.3 Measures

Math self-efficacy was measured using three items on a Likert scale from 1 (Strongly disagree) – 5 (Strongly agree): (i) "I believe I will receive an excellent grade in math"; (ii) "I am certain I can understand difficult material presented in math"; (iii) "I am confident I can learn the basic concepts taught in math".

Maths anxiety was measured on a Likert with scale from 1 (Not at all anxious) – 5 (Very anxious) using three items: (i) "When I think about doing math, I feel …"; (ii) "When the teacher calls on me to answer a math problem, I feel …"; (iii) "When I make a mistake in math, I feel …" .

As the competition heavily revolved around the integrated leaderboards we assessed whether players were motivated by them [*leaderboard motivation:* "Leaderboards were very motivating". Likert scale from 1(strongly disagree) – 5 (strongly agree)]. Related to this, players had to rate how much they enjoyed the game [*game enjoyment*: “I liked the game”. Likert scale from 1(strongly disagree) – 5 (strongly agree)].

Moreover, to better understand whether teams worked together well, we developed a questionnaire to assess *team commitment*, which was measured using four items on a Likert scale from 1 (Strongly disagree) – 5 (Strongly agree): (i) “Our team had clear goals during the competition”; (ii) “We thought it was important to reach the team's goals.”; (iii) “We had a good team spirit.”; (iv) “We wanted to perform well in the math game competition as a team.”.

2.4 Procedure and data collection

Participants had the opportunity to play the game as much as they wanted during a three-week period. Participants could play the game in school or in their free time. During the competition participants were allowed to share tips with their teammates and they were allowed to ask for help from their teacher. After the three-week period of the competition participants were asked to fill in a questionnaire.

3 Results

On average students played through 210 (*SD* = 312, *Median* = 122) number line estimation tasks. Table 1 shows descriptive statistics about student’s performance and self-reported measures.

Table 1. Means and standard deviations of variables and construct reliabilities (n = 271)

Variable	*M*	*SD*	Scale
Math self-efficacy	3.74	1.10	1-5 (α = .86)
Math anxiety	2.04	0.92	1-5 (α = .79)
Team commitment	3.77	0.98	1-5 (α = .86)
Individual rank	360.06	270.56	In this data set 1-891
Team rank	27.81	22.98	In this data set 1-74
Leaderboard motivation	3.25	1.28	1-5
Game enjoyment	3.41	1.14	1-5

By using multiple regression analyses, we aimed at investigating which self-reported measures and leaderboard metrics predicted students’ perceived motivation caused by leaderboards. Accordingly, we used the leaderboard motivation score as dependent variable and following variables as potential predictors in a multiple regression analysis: i) math self-efficacy, ii) math anxiety, iii) team rank, iv) personal rank, v) team commitment, and vi) overall enjoyment of the game. The forced-entry multiple regression model explained 38.49% of variation in perceived leaderboard motivation [$F(6,264)$= 27.99, $p < .001$, *adj.* $R^2 = .37$]. When inspecting the beta weights math anxiety (standardized β = -0.04, *n.s.*) and self-efficacy (standardized β = 0.05, *n.s.*) did not account unique parts of the variance in leaderboard motivation. However, a lower/better team rank (standardized β = -0.18, $p < .01$) and higher enjoyment of the game (standardized β = 0.32, $p < .001$) as well as higher team commitment (standardized β = 0.29, $p < .001$)

were predictive for higher leaderboard motivation. Personal rank did not explain additional unique parts of the variance in leaderboard motivation (standardized β = -0.05, *n.s.*; see Fig. 2).

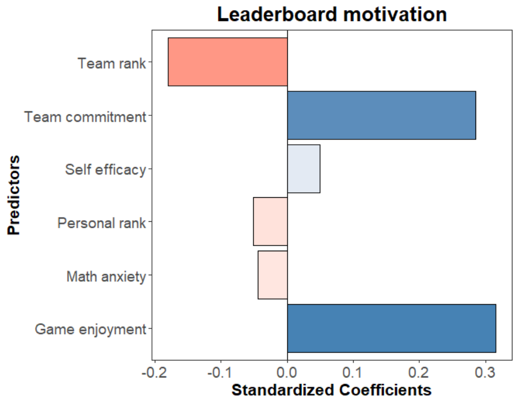

Fig. 2. Standardized beta weights of predictors of leaderboard motivation

4 Discussion

The current study utilized a nation-wide math game competition to realize inter-classroom competition as well as intra-classroom collaboration. Current results indicated that even though leaderboards in the competition were motivating, students with worse team-rank were less motivated. Students personal rank, however, did not contribute additionally to the perceived motivation by the leaderboards but team commitment and overall game enjoyment did. In the following, we will discuss these results in greater detail and provide practical implications.

The leaderboards used in the current math game competition were only partially successful in motivating students. In particular, we observed that students in teams with better team rank were motivated by the leaderboards used. This seemed to be not the case for students in poorly performing teams. Students personal rank did not additionally contribute to leaderboard motivation. Even though this is somewhat in line with previous research on the effects of individual competition [9, 11]. Contrary to our expectations, the integrated collaborative element did not reduce negative effects of leaderboards enough as initially assumed and suggested by previous results on the combination of collaboration and competition [2]. Importantly, team commitment did significantly contribute to perceived leaderboard motivation – even more so than team rank. This is in line with previous research indicating that collaboration is only successful when individuals in team members work in concert and share common goals (e.g., [8, 19, 20]). Additionally, we found overall enjoyment with the game itself to be another contributing factor to the perceived motivation gained from the leaderboards. In contrast, math anxiety and math self-efficacy did not explain additional variance of leaderboard motivation. This might indicate, that leaderboards can motivate players despite of individual differences on these learning related math anxiety and self-efficacy constructs. However, it is not clear whether this can be attributed to the leaderboards itself. For instance, this effect might be related to the general use of games as instructional tools. Because previous studies demonstrated that math anxiety can be lower in game-based than in conventional instructional tools (i.e. paper-based assessment: e.g. [31]).

Fig. 3. Redesign of the leaderboard with personalized feedback and different metrics, i.e. highscore and experience points.

Implications: Although personal rank or performance, respectively, was not a crucial predictor of leaderboard motivation, results of the current study emphasized some of the downsides of an infinite leaderboard design. Results clearly indicated that a worse team-rank negatively affected motivational power of the leaderboard. In its current implementation, leaderboard feedback mechanisms are a double-edged sword offering advantages for well performing teams, but not for teams who are struggling. Leaderboards provide a summative way to provide feedback about players' and teams performance and may facilitate collaboration. However, it is clear that the traditional infinite leaderboard approach – team based or personal – does not motivate all users in the same way.

To overcome this problem, the infinite leaderboards should be redesigned in the way that the position in the leaderboard does not demotivate even the weakest players or teams. That is, that all players or teams could be engaged by showing manipulated (sliced) leaderboards where they are performing relatively well and reaching the top 10 or top 20 does not seem totally impossible. The similar design is sometimes utilized in entertainment games. Further, in social gaming platforms this design is boosted by positioning player's friends just above and below the player. Generally, these kinds of manipulated leaderboards might support the feeling of competence and social interaction more than static infinite leaderboards. Moreover, leaderboards might utilize more and different metrics and thereby provide different goals for the players, such as persistence (e.g. most tasks completed) or gained experience points in a game (see Fig.3).

Additionally, the limited information that traditional leaderboards provide do not facilitate optimal learning or provide support for struggling learners/teams. Therefore, leaderboards or games in general should also provide feedback on players' actions that facilitate reflective thinking on players' conceptions and strategies towards increasing self-efficacy in the learning process [32]. Leaderboards can come with personalized feedback, which has the potential to influence players' performance. For example, a leaderboard could provide details about what a player could improve on and how they could do this (see Fig. 3). Next-generation leaderboards should provide feedback that goes beyond evaluative feedback (e.g. interpretive and supportive). Moreover, future studies need also to consider personality traits of learners as it has been shown, for instance, that introverts and extroverts might experience leaderboards and other game elements differently [33, 34].

Conclusion: Taken together, leaderboards motivated participating students, however, only when the teams of the students were performing well. Importantly, overall game enjoyment as well as team commitment were additional crucial factors contributing to the perceived motivation by the leaderboards. This suggests that in such team-based competitions team commitment needs to be fostered to benefit motivation but even with the collaborative aspect of having teams' negative side-effects of infinite leaderboards cannot be mitigated in its current form.

References

1. Ryan, R.M., Rigby, C.S.: Motivational foundations of game-based learning. In: Plass, J.L., Mayer, R.E., and Homer, B.D. (eds.) Handbook of Game-based Learning. pp. 153–176. MIT Press (2020).
2. Sailer, M., Homner, L.: The Gamification of Learning: a Meta-analysis. Educ. Psychol. Rev. 32, 77–112 (2020).
3. Wouters, P., van Nimwegen, C., van Oostendorp, H., van Der Spek, E.D.: A meta-analysis of the cognitive and motivational effects of serious games. J. Educ. Psychol. 105, 249–265 (2013).
4. Clark, D.B., Tanner-Smith, E.E., Killingsworth, S.S.: Digital Games, Design, and Learning: A Systematic Review and Meta-Analysis. Rev. Educ. Res. 86, 79–122 (2016).
5. Byun, J., Joung, E.: Digital game-based learning for K-12 mathematics education: A meta-analysis. Sch. Sci. Math. 118, 113–126 (2018).
6. Graesser, A.C.: Reflections on Serious Games. In: Wouters, P. and van Oostendorp, H. (eds.) Instructional Techniques to Facilitate Learning and Motivation of Serious Games. pp. 199–212. Springer International Publishing, Cham (2017).
7. Cagiltay, N.E., Ozcelik, E., Ozcelik, N.S.: The effect of competition on learning in games. Comput. Educ. 87, 35–41 (2015).
8. Plass, J.L., O'Keefe, P. a., Homer, B.D., Case, J., Hayward, E.O., Stein, M., Perlin, K.: The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. J. Educ. Psychol. 105, 1050–1066 (2013).
9. Lin, C.-H., Huang, S.-H., Shih, J.-L., Covaci, A., Ghinea, G.: Game-Based Learning Effectiveness and Motivation Study between Competitive and Cooperative Modes. In: 2017 IEEE 17th International Conference on Advanced Learning Technologies (ICALT). pp. 123–127. IEEE (2017).
10. Vandercruysse, S., Vandewaetere, M., Cornillie, F., Clarebout, G.: Competition and students' perceptions in a game-based language learning environment. Educ. Technol. Res. Dev. 61, 927–950 (2013).
11. ter Vrugte, J., de Jong, T., Vandercruysse, S., Wouters, P., van Oostendorp, H., Elen, J.: How competition and heterogeneous collaboration interact in prevocational game-based mathematics education. Comput. Educ. 89, 42–52 (2015).
12. Chen, C.-H., Shih, C.-C., Law, V.: The effects of competition in digital game-based learning (DGBL): a meta-analysis. Educ. Technol. Res. Dev. (2020).

13. Nebel, S., Schneider, S., Beege, M., Rey, G.D.: Leaderboards within educational videogames: The impact of difficulty, effort and gameplay. Comput. Educ. 113, 28–41 (2017).
14. Hattie, J., Timperley, H.: The Power of Feedback. Rev. Educ. Res. 77, 81–112 (2007).
15. Nebel, S., Beege, M., Schneider, S., Rey, G.D.: The higher the score, the higher the learning outcome? Heterogeneous impacts of leaderboards and choice within educational videogames. Comput. Human Behav. 65, 391–401 (2016).
16. Kluger, A., DeNisi, A.: The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. Psychol. Bull. II, 254–284 (1996).
17. Wang, H., Sun, C.T.: Game reward systems: Gaming experiences and social meanings. Proc. DiGRA 2011 Conf. Think Des. Play. (2011).
18. Rigby, C.S., Ryan, R.M.: Glued to games: How video games draw us in and hold us spellbound. Praeger, Santa Barbara, CA (2011).
19. Lou, Y., Abrami, P.C., Spence, J.C., Poulsen, C., Chambers, B., D'Apollonia, S.: Within-Class Grouping: A Meta-Analysis. Rev. Educ. Res. 66, 423 (1996).
20. Slavin, R.E.: Cooperative learning and student achievement. Educ. Leadersh. 46, 31–33 (1988).
21. Hung, C.-M., Huang, I., Hwang, G.-J.: Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. J. Comput. Educ. 1, 151–166 (2014).
22. Skaalvik, E.M., Federici, R.A., Klassen, R.M.: Mathematics achievement and self-efficacy: Relations with motivation for mathematics. Int. J. Educ. Res. 72, 129–136 (2015).
23. Peters, M.L.: Examining the relationships among classroom climate, self-efficacy, and achievement in undergraduate mathematics: A multi-level analysis. Int. J. Sci. Math. Educ. 11, 459–480 (2013).
24. Pajares, F., Miller, M.D.: Role of self-efficacy and self-concept beliefs in mathematical problem solving: A path analysis. J. Educ. Psychol. 86, 193–203 (1994).
25. Clute, P.S.: Mathematics Anxiety, Instructional Method, and Achievement in a Survey Course in College Mathematics. J. Res. Math. Educ. 15, 50 (1984).
26. Siegler, R.S., Opfer, J.E.: The Development of Numerical Estimation: Evidence for Multiple Representations of Numerical Quantity. Psychol. Sci. 14, 237–243 (2003).
27. Ninaus, M., Kiili, K., McMullen, J., Moeller, K.: Assessing fraction knowledge by a digital game. Comput. Human Behav. 70, 197–206 (2017).
28. Kiili, K., Moeller, K., Ninaus, M.: Evaluating the effectiveness of a game-based rational number training - In-game metrics as learning indicators. Comput. Educ. 120, 13–28 (2018).
29. Fazio, L.K., Kennedy, C.A., Siegler, R.S.: Improving Children's Knowledge of Fraction Magnitudes. PLoS One. 11, e0165243 (2016).
30. Kiili, K., Ojansuu, K., Lindstedt, A., Ninaus, M.: Exploring the Educational Potential of a Game-Based Math Competition. Int. J. Game-Based Learn. 8, 14–28 (2018).
31. Kiili, K., Ketamo, H.: Evaluating Cognitive and Affective Outcomes of a Digital Game-Based Math Test. IEEE Trans. Learn. Technol. 11, 255–263 (2018).
32. Shute, V.J.: Focus on Formative Feedback. Rev. Educ. Res. 78, 153–189 (2008).
33. Codish, D., Ravid, G.: Personality Based Gamification – Educational Gamification for Extroverts and Introverts. CHAIS '14 - Conf. Study Innov. Learn. Technol. Learn. Technol. Era. 36–44 (2012).
34. Tondello, G.F., Wehbe, R.R., Diamond, L., Busch, M., Marczewski, A., Nacke, L.E.: The Gamification User Types Hexad Scale. Proc. 2016 Annu. Symp. Comput. Interact. Play - CHI Play '16. 229–243 (2016).