Flow experience and situational interest in an adaptive math game

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Abstract. The purpose of this study was to investigate flow experience and situational interest in a math learning game that included adaptive scaffolding. Fifty-two Finnish 5th graders played the game about fractions at home during COVID-19 enforced distance learning. The results showed that flow experience correlated positively with situational interest. Importantly, a deeper analysis of the Flow Short Scale (FSS) subscales revealed that only absorption by activity but not fluency of performance explained variance in situational interest. That is, at least in game-based adaptive learning, situational interest is mostly related to immersive aspects of flow. Results also revealed that students with better in-game performance had higher flow experiences, but their levels of prior knowledge were not related to flow levels. In contrast, students with lower prior fraction number knowledge showed higher situational interest, which might be partly attributed to the additional game elements provided to struggling students in the form of adaptive scaffolds. Moreover, the study demonstrated that the developed adaptive scaffolding approach and in-game self-reporting measures worked well. Finally, the implications of these findings for flow experience and situational interest research in game-based learning context are discussed.

Keywords: Flow experience, Situational interest, Game-based learning, Adaptive scaffolding, Mathematics.

1 Introduction

Digital learning environments and game-based learning offer various tools to support learning in students, such as real-time feedback and adaptivity. Recent research indicates that adaptive learning can be more effective than non-adaptive forms of learning (for a review, see [1]) and might be particularly useful for challenging topics. In the domain of mathematics education, fractions are considered to be one of the most difficult topics and many students struggle to understand fraction magnitudes (e.g. [2]). Appropriate adaptive feedback or scaffolds might be helpful to support students in learning fractions, including increasing their engagement. Scaffolding refers to support provided during the learning processes to assist a student in achieving something that would be hard or even impossible without assistance [3]. That is, scaffolding temporarily reduces the demands of the task to facilitate learning. With respect to game-based learning, the extended three-channel model of flow [4] suggests that scaffolding may also increase players' engagement as it helps to balance the challenge and skills of struggling players leading to higher possibilities for flow experiences.

1.1 Playing experience

The evaluation of playing experience is important in educational game design. The enjoyment level that game-based learning produce is a key factor in determining whether a player will be engaged in the gameplay and achieve the desired learning objectives [4]. Flow experience is one of the most popular constructs to describe playing experience [4], [5] and it can be used to evaluate the quality of the playing experience as well as game-based learning solutions [4], [6]. Flow refers to optimal experience, where an activity is so pleasant that a person wants to perform it again and again without being concerned with what he will get out of it [7]. “The state of flow is characterized by a combination of several specific aspects, namely, (1) concentration, (2) a merging of action and awareness, (3) reduced self-consciousness, (4) a sense of control, (5) a transformation of time, and (6) an experience of the activity as intrinsically rewarding” [8]. Flow can be considered as a special form of enjoyment [9], [10] involving several requirements such as clear goals, immediate feedback, undivided attention to the task at hand, and skills matching the challenge or demands of the activity. Flow experience seems to be positively related to playing performance (e.g. [11], [4]) and can be divided into dimensions, such as fluency of performance and absorption by activity [12].

Situational interest is another construct that may explain students’ engagement in game-based learning [13]. Situational interest refers to attentional and emotional reactions induced by the environment, for example, a learning environment (e.g. [14]). There is a growing body of literature suggesting that situational interest increases attention, cognitive processing, and persistence (e.g. [15]) that seem to be in line with several characteristics associated with flow experience. Although excitement and fascination are common characteristics of situational interest, it is distinct from enjoyment, as it also includes elements relating to the subjective value of the interest object or involvement in the activity [16].

1.2 Present study

In this paper, we examine flow experience and situational interest in a math game that includes adaptive scaffolding. One aim of game-based learning is to elicit situational interest and flow experience, but to our knowledge, the relation of these constructs has not been examined in a game-based learning context yet. Further, it is of great interest to game designers and learning material producers to understand how the level of prior knowledge and in-game performance are related to situational interest and flow experience in learning solutions that include adaptive scaffolding features, as this knowledge might help to optimize the playing experience. Therefore, the aim of the present study was to investigate relations between prior knowledge, game performance, flow experience, and situational interest. Additionally, the implementation of the developed adaptive scaffolding system, and in-game self-report measures was evaluated.

To investigate the associations of flow with prior knowledge, game performance, and situational interest, we had three hypotheses. (H1) As flow and situational interest constructs share several common characteristics, we did expect that flow experience and situational interest have a positive relation. (H2) As subjective flow experience should be associated with high performance [12], we did expect that in-game performance and the level of flow are positively related. According to the knowledge-deprivation hypothesis, perceived lack of knowledge leads to situational interest [17]. (H3) Thus, we did expect that situational interest and prior knowledge are negatively related.

2 Method

2.1 Participants

This study included 52 fifth graders (age approx. 10-11 years) from eight schools in Helsinki, Finland. The study was approved by the city of Helsinki's ethical board and all students had parental permission. Originally, over 200 students had permission to participate, but as the study was held in spring 2020, the COVID-19 pandemic, unfortunately, forced the schools into a lockdown, which greatly affected our data gathering.

2.2 Description of the game

We used our math game research environment, an extended version of the Semideus game engine [e.g. 11], to create a Number Trace fraction game for this study. The basic mechanic of the game is based on a number line estimation task, which requires users to indicate the position of a given number on a horizontal line with only its endpoints specified (e.g., where goes 4/5 on a number line ranging from 0-1). Ample research indicates that the number line estimation task can be used to assess, as well as train, students' understanding of number magnitude (for a review, see [18]).

The player controls a dog character and tries to locate bones hidden in the forest. The location of the bone is displayed as a symbolic fraction, visual representation, or mixed number. The player has to estimate the location and walk the dog to it. On some tasks, the walking is replaced with sequential jumping where the jump length is fixed to some mathematically meaningful sequence (usually unit fraction of the task). For example, if the estimated value is 3/7, the dog would need three jumps (3 * 1/7) to move from the left side of the number to the bone. Some tasks also included enemies that had to be avoided or destroyed. The number line ranged either from 0 to 1 or from 0 to 5.

Adaptive scaffolding was based on players' competences on three categories: fractions on a number line from 0 to 1, fractions on a number line from 0 to 5, and mixed numbers. The competence level of the category was the mean of student's five most recent answers to tasks relevant to the category. Adaptive scaffolding was triggered to assist the player based on their competence levels. That is, if the system identified that a player had minor difficulties with a certain competence, in subsequent tasks dealing with the same competence, scaffolding would trigger and assist the player if the initial answer was incorrect. If the player had more severe difficulties, the assistance was provided immediately at the beginning of the task.

The scaffolds included in the game:

- Shows the improper fraction as a mixed number. For example: 5/2 → 2 ½
- Shows the fraction number as a pie graph to provide visual representation.
- Subtracts the fraction to the smallest common factor. For example: 4/8 → 1/2
- Summons birds to divide the number line into equal sections based on the denominator of the fraction to be estimated. For example: 3/8 → divide into eight sections
- Summons worms to visualize improper fractions or mixed numbers (see Figure 1).
- Jumping shoes activates the jump movement (as described above).

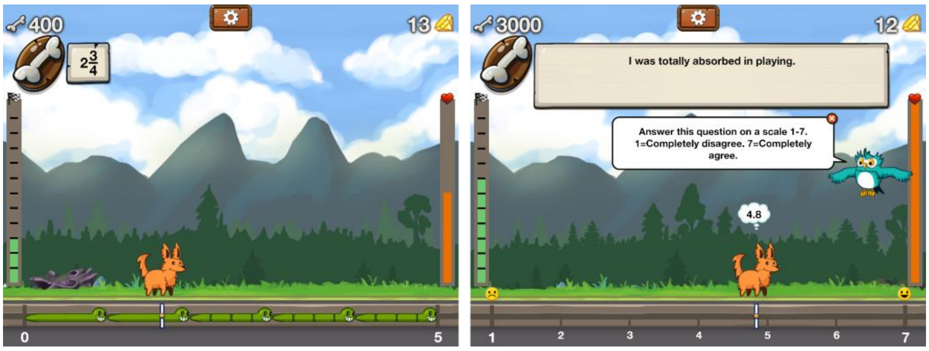

Fig. 1. *On the left*: A game task on a number line ranging from 0 to 5. The player has to estimate a mixed number 2 ¾. A scaffold "Worm" has been activated, which fills the number line with worms thus dividing it into five sections. *On the right*: A task from the flow questionnaire level. The answer is given on a continuous scale from 1 to 7 with the exact value shown.

The game also supports text-based questions that were used to implement in-game questionnaires (self-report measures). Instead of an estimation task, the student would see a question. The answering is still done using the number line by walking the dog character to a position that reflects the wanted value. The exact value is clearly visible above the dog, so the student knows exactly what he/she is about to answer. The number line range defines the used answer scale. For example, range from 1 to 5 means the question has a continuous scale from 1 to 5.

2.3 Measures

Prior knowledge was measured with a pretest that was conducted using a browser-based, non-gamified platform, developed by the authors. It contained eight number line items, where the student estimated the location of a fraction by dragging a marker on a number line. The answer was deemed correct if its accuracy was at least 92% for number lines ranging from 0-1. For number lines ranging from 0-5, an accuracy of 90% was enough for the answer to be considered correct. In addition, there were six ordering items, where the student had to drag boxes (3 or 4 per task), each containing a fraction or a mixed number, into an ascending order based on given values. Prior knowledge was calculated by taking the percent of correct answers.

Game performance in the Number Trace game was measured using the estimation accuracy percent of the initial answer on each task in levels 10-18 (see procedure). If the student answered incorrectly, the game offered another attempt, but the latter answer was not taken into account in our performance measurements. *Scaffold count* was calculated by tracking the number of tasks, where the student was scaffolded.

Situational interest was measured with a question "The tasks of this game level were interesting", which was asked at three different stages of the levels included in this study. *Flow experience* was measured with a slightly modified version of the Flow Short Scale [12] using a total of 10 items (6 items for fluency of performance; 4 items for absorption by activity). The statements were changed to past tense and made the activity to refer to game playing (see Appendix A).

2.4 Procedure

The teachers were supposed to hold five school classes (45 minutes each) within a four-week period, in which the students would complete the pretest, and play the Number Trace game. During this period, the teachers were instructed not to teach fractions in any other way. But, as mentioned, school lockdowns interrupted the intervention, which forced us to re-evaluate our participant inclusion criteria for this study. Some teachers decided not to continue playing, but with the classes that continued the playing at home, we faced another issue: as different classes had progressed at different schedules, there were some variations on how far the students had progressed on the game content before the lockdown that we had to take into account.

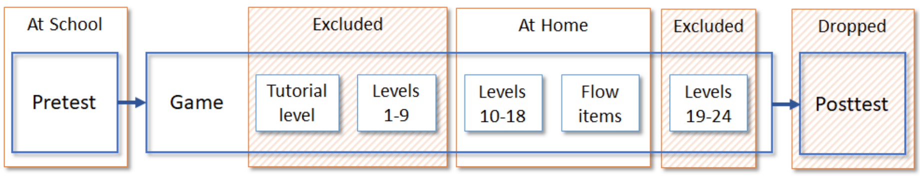

Fig. 2. The planned procedure of the study, which was interrupted by distance learning due to COVID-19. The parts marked with "Excluded" were not included in the data used in the study. We were unable to conduct the posttest. Situational interest item in levels: 10, 13 and 16.

Every student had completed the pretest at school. As Figure 2 shows, we included levels 10-18 and the subsequent flow questionnaire level in the data. The levels 1-9 had too much variance in had those been played at school or at home and therefore had to be omitted. Levels 19-24 were excluded because too many students had not reached those during the intervention. Each level contained 10 fraction estimation tasks, meaning there were a total of 90 tasks included in this study. Of these tasks, 60 had potential scaffolding available. We were unable to conduct the planned posttest.

Situational interest was measured in levels 10, 13 and 16 using an in-game question (see section 2.2). After level 18, the students completed a level that included the modified Flow Short Scale. The level started with one training item, which was not included in the data, to remind students how to answer the in-game questionnaire items, and to clarify that tasks in this level are not like the previous level's mathematical tasks.

3 Results

The descriptive statistics and reliabilities of the used scales for the measured variables are listed in Table 1. The modified Flow Short Scale (and its subscales), the situational interest items, and the pretest's prior knowledge questions all had at least good internal consistency (Cronbach's alpha). Additionally, we explored the data for anomalies, such as answering patterns and too short answer durations. As a result, we identified two students, who both had very short answering durations and all their answers were at default value. They were omitted from the flow experience measurements. It seems that our in-game self-reporting measures worked well, as we had to exclude only two students and the internal consistency of the measures were good.

Table 1. Descriptive statistics and reliabilities of the used scales for the measured variables.

	Mean	SD	Median	Scale
Flow experience	4.44	1.23	4.44	1-7 (α = .870)
Fluency of performance	4.72	1.23	4.85	1-7 (α = .852)
Absorption by activity	3.87	1.52	4.04	1-7 (α = .765)
Situational Interest	3.36	1.08	3.55	1-5 (α = .773)
Prior Knowledge	52.3	25.8	50.0	0-100% (α = .836)
Game Performance	93.9	2.04	93.9	0-100%
Scaffold Count	5.85	6.07	4.00	-

The combined average of all flow items was $M = 4.44$ ($SD = 1.23$). This was slightly below the overall Flow Short Scale mean (4.7) attained with various activities and across various previous studies [12]. Fluency of performance subscale ($M = 4.72$, $SD = 1.23$) scored above the overall mean, while absorption by activity subscale ($M = 3.87$, $SD = 1.52$) scored below. The correlation between the subscales was large ($r = .60$, $p < .001$) that is consistent with [12].

In this study, the correlation between several variables, such as flow experience, was studied (see Table 2). In line with *Hypothesis 1*, we found that flow experience was related to situational interest ($r = .41$, $p = .003$). In order to get a deeper understanding of this relation, we ran a multiple regression analysis with situational interest as a dependent variable and the two subscales of flow - i.e. fluency of performance and absorption by activity - as predictors. The results of the forced-entry multiple regression indicated that absorption by activity (*standardized Beta* = 0.59, p < .001) explained 27.2% of the variance [F(2,49) = 9.15, p < .001; adjusted R^2 = .24]. Fluency of performance, however, did not account for a unique part of the variance in situational interest (*standardized Beta* = -0.13, p = .41). In line with *Hypothesis 2*, we found a correlation, albeit only a small one, between experienced flow and in-game performance (r = .33, p = .016). This suggests that the students with better in-game performance, had a higher experience of flow.

Table 2. Correlations (Pearson's r †) between the measured variables.

		1	2	3	4	5
1	Flow Experience	1				
2	Situational Interest	.414**	1			
3	Prior Knowledge	.092	-.380**	1		
4	Game Performance	.329*	.016	.368**	1	
5	Scaffold Count	-.176	.065	-.386**	-.659***	1

Note. * p < .05, ** p < .01, *** p < .001

† The same analysis with Spearman's correlation did not change the results substantially.

Addressing *Hypothesis 3*, we found a medium negative correlation (r = -.38, p = .002) between prior knowledge and experienced situational interest. Students with less prior knowledge were more likely to experience higher situational interest than students with higher prior knowledge. However, there was no correlation (r = .02, p = .909) between situational interest and in-game performance.

Out of the 90 total tasks included in the study's game level, 60 tasks included scaffolding features. The best players completed the game without seeing any scaffolds, while the most struggling student saw scaffolds on 23 tasks (M = 5.85, SD = 6.07). As designed for, the adaptive scaffolding system provided more scaffolds to students with weaker prior knowledge as indicated by the medium negative correlation (r = -.39, p = .005) between scaffold count and prior knowledge. The large negative correlation (r = -.66, p < .001) between scaffold count and in-game performance was also expected as the scaffolds were targeted for low performing players.

Finally, a paired-samples t-test was conducted to compare estimation accuracy in the pretest and in the game levels (10-16) that included similar estimation tasks. Only the first answer for each task was included. The answers affected by scaffolds (0.5% of all answers) were excluded. The accuracy was significantly higher in the game (M = 94.1, SD = 1.82) than in the pre-test (M = 84.3, SD = 7.18), t(51) = 10.6, p < .001, d = 1.47.

4 Discussion and conclusion

Player enjoyment is a crucial goal of games and game-based learning. If players do not enjoy the game, they will not play the game at all or they will play the game only superficially without investing cognitive resources to consider the challenges and the content of the game deeply enough. The purpose of the current study was to build a better understanding of engagement in game-based learning. Particularly, we investigated students' playing experience in an adaptive math game through flow experience and situational interest and reflected these findings in relation to students' prior knowledge and in-game performance.

In line with *Hypothesis 1*, we found a positive relation between flow experience and situational interest, indicating that these constructs are partly parallel. Importantly, a more detailed analysis revealed that the flow subscale, absorption by activity, explained situational interest, while the fluency of performance subscale did not contribute to it. As expected in *Hypothesis 2,* we found that students who performed better in the game also experienced more flow, which is in line with previous research [12]. This would support the use of adaptive scaffolds as they may help the students with less competence to perform better and thus, presumably, experience higher flow as well. In contrast, in-game performance was not related to situational interest. In fact, this can partly explain why fluency of performance subscale did not predict situational interest. Although flow was not related to prior knowledge, it seems that flow is more competence-oriented construct than situational interest. With respect to *Hypothesis 3*, our finding that prior knowledge was inversely related with situational interest further supports our inference about the meaning of competence in flow and situational interest. The results are in accordance with Rotgans and Schmidt's [17] study indicating that knowledge accumulation tends to be inversely related to situational interest. Further, their study indicates that perceived lack of knowledge leads to situational interest, which in turn leads to learning. Thus, it is important that the game provides immediate feedback on players' competences, which helps to trigger and maintain situational interest.

In the current study, learning analytics of the game was successfully used to identify students that needed assistance. Consequently, weaker students were scaffolded, which balanced the game's challenge for them. As mentioned, students with lower prior knowledge experienced higher situational interest, which we, in addition to lack of knowledge, attribute to the additional game mechanics offered to them through adaptive scaffolding. Likely, the used scaffold mechanics have triggered situational interest in players as they may have perceived the scaffolds as novel and personally relevant events that have also helped them to identify the existing knowledge gaps. The downside of scaffolding is that it only supports students who need assistance. We believe that flow and situational interest could have been facilitated with adaptive features that consider also the needs of well-performing students. In the current implementation, better-performing students missed some of the game features as the scaffolds were not shown to them. This could be compensated by including features that increase the difficulty, like extra enemies to make playing harder, or ways to increase the mathematical difficulty. For example, one of the scaffolds subtracts the fraction number to the lowest common factor. This could be reversed by expanding the original fraction number into "larger" and more difficult factors. With respect to better-performing students, the increased difficulty would probably facilitate flow as the challenge would be better balanced with skills, and the novel features and possibly aroused knowledge gaps would facilitate also situational interest.

We used in-game questions to measure flow and situational interest. The study demonstrated that we managed to successfully utilize the game's core mechanics to embed self-report items into the game. The answering was fluid and did not distract the students or disrupt the playing experience. Only the answers of two students had to be removed from the analyses, as they were clearly invalid. That is, the results suggest that such in-game self-report measures do not encourage careless responding. In fact, our approach was an effective way to collect the students' experiences during gameplay as answering the questions was mandatory in order to progress in the game. The in-game approach works well to measure especially situational interest, as it allows an easy and non-distracting way to collect repeated measures providing more exhaustive insights in what happens during the gameplay compared to common before or after game measurement approaches.

The limitations of this study revolve much around the pandemic-enforced school lockdowns, which altered the research design quite a bit from the original. First of all, it greatly reduced the sample size (N=52), reducing the statistical power of the study. It also forced us to exclude some early game levels from our analyses that complicates the interpretation of the results. We were also unable to conduct the planned posttest, so we had to evaluate learning outcomes by comparing the estimation accuracy of the pretest to an "ad-hoc posttest", i.e. estimation accuracy of the selected levels of the game. This comparison indicated that playing the Number Trace game significantly improved students' conceptual fraction knowledge. However, the large improvement needs to be interpreted cautiously as the tasks of the pretest and game were not entirely comparable. Further, the lack of a proper posttest also meant that we could not include a control group in the analyses. Even though we did manage the difference in playing surroundings by making sure that the measured game content was not played partly at school and partly at home, but only at home, we expect that there were variations at students' home surroundings. Things like distractions, technical issues, or parental help during the play might have affected the results.

To conclude, the current study advances the game-based learning field by shedding light on the unaddressed relationship between situational interest and flow experience. The results indicated that although these constructs are positively related, there are also differences. It seems that the immersive aspects of flow experience, rather than the competence related aspects, are associated with situational interest. Unlike flow, situational interest seems to be inversely related to knowledge accumulation and is triggered by perceived lack of knowledge. Thus, adaptation of feedback (ensuring that player perceives knowledge gaps) should facilitate situational interest, and challenge adaptation (balancing challenge to player's skills) should facilitate flow. On the practical side, as both the flow and situational interest constructs aim to explain why people engage in activities, they are useful measures for game design that can be used to evaluate playing experience as well as the quality of game-based learning solutions. Further, the results provide some validation for the proposed use of game's core mechanics to collect self-reported playing experience data.

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References

1. Aleven, V., McLaughlin, E. A., Glenn, R. A., Koedinger, K. R.: Instruction based on adaptive learning technologies. Handbook of research on learning and instruction, 522-560 (2016).
2. Siegler, R. S., Fazio, L. K., Bailey, D. H., Zhou, X.: Fractions: The new frontier for theories of numerical development. Trends in Cognitive Sciences 17(1) (2013).
3. Wood, D., Bruner, J. Ross, G. The role of tutoring in problem solving. Journal of Child Psychology and Psychiatry, 17, 89–100 (1976).
4. Kiili, K., Lainema, T., de Freitas, S., Arnab, S.: Flow framework for analyzing the quality of educational games. Entertainment computing 5(4), 367-377 (2014).
5. Procci, K., Singer, A.R., Levy, K.R., Bowers, C.: Measuring the flow experience of gamers: an evaluation of the DFS-2. Computers in Human Behavior 2012 conference 28(6), 2306–2312 (2012).
6. Perttula, A., Kiili, K., Lindstedt, A., Tuomi, P.: Flow experience in game based learning – a systematic literature review. International Journal of Serious Games 4(1), 57-72 (2017).
7. Csikszentmihalyi, M.: Flow: The Psychology of Optimal Experience. Harper Perennial, New York. (1991).
8. Keller, J., Landhäußer, A.: The flow model revisited. In: Engeser, S. (ed.) Advances in flow research, pp. 51-64. Springer, New York, NY (2012).
9. Baumann, N., Lürig, C., Engeser, S.: Flow and enjoyment beyond skill-demand balance: The role of game pacing curves and personality. Motivation and Emotion 40(4), 507–519 (2016).
10. Kiili, K., Lindstedt, A., & Ninaus, M.: Exploring characteristics of students' emotions, flow and motivation in a math game competition. In: Koivisto, J., Hamari, J. (eds.) Proceedings of the 2nd International GAMIFIN Conference, pp. 20-29. CEUR Workshop Proceedings, Pori, Finland (2018).
11. Kiili, K., Ketamo, H.: Evaluating cognitive and affective outcomes of a digital game-based math test. IEEE Transactions on Learning Technologies 11(2), 255 - 263 (2018).
12. Engeser, S., Rheinberg, F.: Flow, performance and moderators of challenge-skill balance. Motivation and Emotion 32(3), 158-172 (2008).
13. Eccles, J. S., Wigfield, A.: Motivational beliefs, values, and goals. Annual review of psychology 53(1), 109-132 (2002).
14. Knogler, M.: Situational interest: A proposal to enhance conceptual clarity. In: O'Keefe P. A., Harackiewicz J. M. (Eds.) The science of interest, pp. 109–124. Springer International Publishing (2017).
15. Hidi, S.: Interest, Reading, and Learning: Theoretical and Practical Considerations. Educational Psychology Review 13(3), 191–209 (2001).
16. 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. Journal of educational psychology 105(4), 1050-1066 (2013).
17. Rotgans, J. I., Schmidt, H. G.: Situational interest and learning: Thirst for knowledge. Learning and Instruction 32, 37-50 (2014).
18. Schneider, M., Thompson, C.A., Rittle-Johnson, B.: Associations of magnitude comparison and number line estimation with mathematical competence: a comparative review. In: Lemaire, P. (ed.) Cognitive development from a strategy perspective: A festschrift for Robert S. Siegler. Psychology Press, London (2018).

Appendix

Appendix A. Modified Flow Short Scale questions

	Question	Fluency of performance	Absorption by activity
1	The game provided just the right amount of challenge.		x
2	My thoughts/activities ran fluidly and smoothly.	x	
3	I didn't notice time passing.		x
4	I could concentrate on playing.	x	
5	My mind was completely clear.	x	
6	I was totally absorbed in playing.		x
7	The right thoughts/movements occurred of their own accord.	x	
8	I knew what I had to do in the game.	x	
9	I felt that I had everything under control.	x	
10	I was completely lost in thought.		x