Gamifying Maths Assessment:
Bringing Together Flow and Zone of Proximal Development

Harri Ketamo
Satakunta University of Applied Sciences

Keith Devlin
Stanford University

Abstract: Games are everywhere. Billions of kids all over the world are playing entertain games. At the same time each player enriches commercial marketing datasets from which marketing companies produce an optimal marketing campaign for specific geographical region and customer segment. All this is done in individual, national and global level. Unlike marketing, learning is a complex phenomena and it's very challenging to produce instruments that connects single learning event into more general performance metrics. In this study we build higher level metrics for assessing pupils with games. The metrics is based Conceptual Change that is revealed by mining the game activities. In individual level we can point out the Zone of Proximal Development as well as anxiety and boredom. In Flow theory anxiety and boredom are consequence of unbalanced skills and competence. Finally, in gamified environments the Zone of Proximal Development can be seen as a parallel concept to Flow and so Flow can also be seen an indicator for learning.

Keywords: Gamification**,** Assessment, Learning Analytics, Mathematics Learning

INTRODUCTION

Gamification is often defined as "the use of game design elements in non-game contexts" (e.g. Deterding, Sicart, Nacke, O'Hara & Dixon, 2011; Deterding, Björk, Nacke, Dixon & Lawley 2013). Groh (2012) extends the definition by separating the concept gamification from concept of serious games and playful interaction, and highlights the Flow -properties (e.g. Csikszentmihalyi 1991) of gamification: optimal challenge, clear goals, instant feedback and autonomy in play.

Gamification is applied in practice in various contexts: in designing engaging business software (e.g. Kumar 2013), effective logistics processes (e.g. Hense, Klevers, Sailer, Horenburg, Mandl, Günthner 2014), user experience design (e.g. Deterning & al. 2011) as well as personalized health solutions (e.g. McCallum 2012). Learning is one of the biggest domains in gamification, but when excluding serious games, there is less applications left. One of the most popular approaches are Badges (e.g. Hakulinen & Auvinen 2014), which can be seen as combination of game-like reward mechanism and competence recognition. The various national assessments most often focuses on evaluating pre-defined competences like adding with numbers 0-20, so badges can be seen similar measure.

In international level assessment performance measures, like Programme for International Student Assessment (PISA), Trends in International Mathematics and Science Study (TIMSS) and Progress in International Reading Literacy Study (PIRLS) ranks the countries based on their educational system's performance. However, these activities are heavy to run: it requires years of work for thousands of people to collect, analyze and report the data. Furthermore, the results are always two years ole when published and there are tens of missing countries. Finally, the biggest missing part is the understanding how to improve the system in national or individual level.

Gamified assessment can be seen partial answer to this: distribution of the assessment (i.e. games) can be done globally without any extra effort because of appstores: There are currently billions of kids who plays online games all over the world. When going online gaming type of measures, the data is always in real time and so enabling data driven management of education. Most important feature is the capability to give suggestions how to improve curriculum, tradition in teaching or learning materials in use. Furthermore, real time analytics enables individual level recommendations and adaptation in learning.

However, there are numerous challenges: unlike marketing, learning is a complex phenomena and it's very challenging to produce instruments that connects single learning event into more general performance metrics. In this study we design higher level metrics based on Conceptual Change and Flow which are revealed by mining the game activities.

Flow experience (Csikszentmihalyi 1991) can be defined through it's observable factors: 1) clear goals and sub-goals, 2) real-time feedback that is relevant for receiveing goals, 3) challenge is in balanced with person's skill level, 4) the feeling of being in control and 5) focused attention with maybe loss of self-consciousness. Although Flow is originally designed for sport-related activities, it has been succesfully adopetd to learning sciences for decades (e.g. Kiili 2005; Kiili 2007), especially from skill-challenge factor point of view (figure 1). However, the focused attention -factor could be different between learning and sports. According to Tenenbaum (2001) activity's intensity affects on focus of attention. The research on sports has shown that when the physical workload increases, attention allocation shifts from dissociation to association (e.g. Tenenbaumb & Connollya 2008; Hutchinsona & Tenenbaum 2007). This is challenging when combining sports and learning (Singlair, Hingston & Masek 2007). When focusing only in learning, the focused attention is more related to motivation than loss of self-consciousness (e.g. Kiili & Ketamo 2007; Kiili, Ketamo & Kickmeier-Rust 2014).

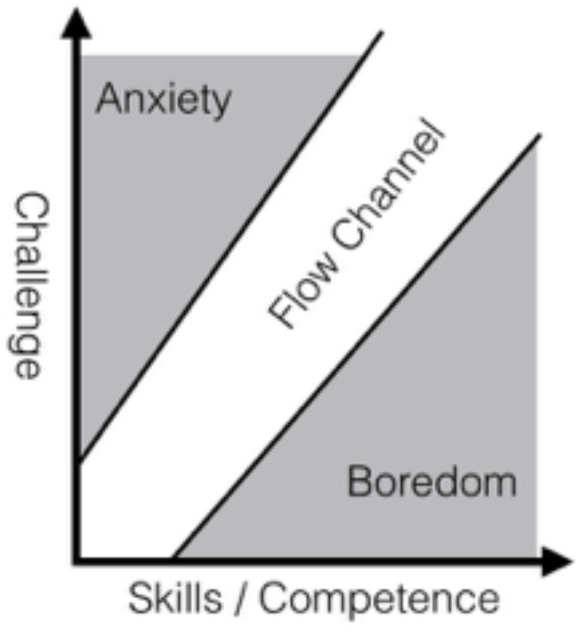

Figure 1. Skill - Challenge factor of Flow Experience.

In terms of constructive psychology of learning, people actively construct their own knowledge through interaction with the environment and through reorganization of their mental structures. The key elements in learning are accommodation and assimilation. Accommodation describes an event when a learner figures out something new, which leads to a change in his/her mental conceptual structure. Assimilation describes events when a learner strengthens his/her mental conceptual structure by means of new relations (Mayer 2004).

Most learning theories rely on the assumption that concepts change through an enrichment of prior knowledge (Vosniadou, 2007). Conceptual change differs from these learning theories, because it cannot be achieved through additive mechanisms involving only the enrichment of pre-existing knowledge. In fact, the conceptual change approach emerged from an effort to explain the radical reorganization of conceptual knowledge and acquire an understanding of difficult concepts (Vosniadou, 2007). In other words, conceptual change can be seen as a radical accommodation process. Conceptual change has its roots in realm of science, but it is applicable to mathematics (Stafylidou & Vosniadou, 2004; Vosniadou & Verschaffel, 2004).

Zone of Proximal Development (Vygotsky 1962; Vygotsky 1978) describes conditions or limits where learner is capable to do/learn something on her/his own (figure 2). In this context boredom is related to tasks that are routine-type and non-challenging, while anxiety is related to activities that requires supervision to be completed.

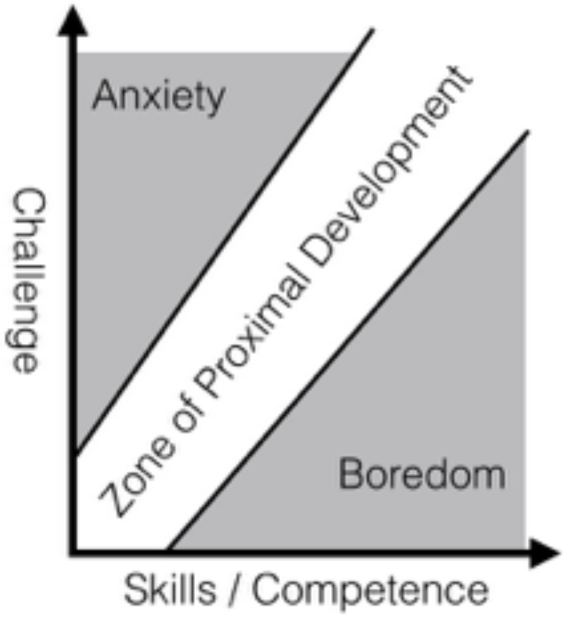

Figure 2. Zone of Proximal Development

The connective factor between Zone of Proximal Development, Conceptual Change and Flow is the balance between challenge and skills. The similarity of these concepts has been shown in previous research (Ketamo & Multisilta 2003; Ketamo 2003) in gamified environments we can 1) approximate challenge by measuring delays between activities in game play in short (e.g. 30sec) intervals and 2) approximate skills by measuring percentile share of correct answers during the same interval.

When the delays between activities in game play are short enough and the share of correct answers is low, a person can still learn something, even remarkable, new skills. In the same way, if the delays between activities in game play are long, but the share of correct answers is high, person is in conceptual change - mode. However, if delays between activities in game play are short and share of correct answers is high, the person is not learning anything new, she/he is doing routine-type of non-motivating tasks.

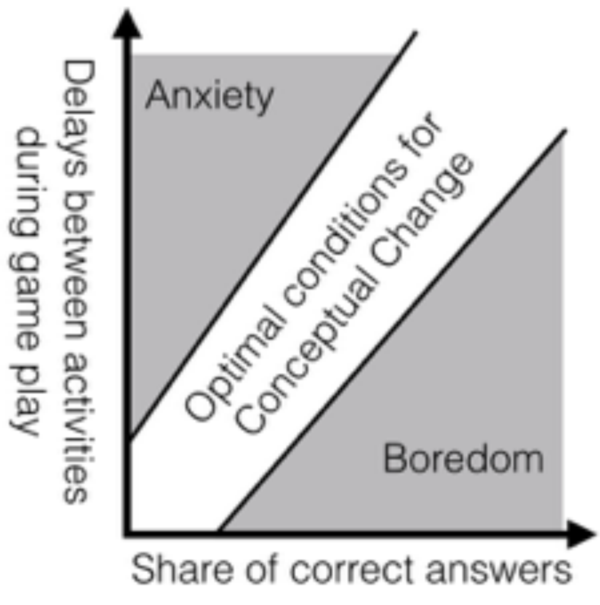

Figure 3. Conceptual change’s similarities to Flow and Zone of Proximal Development.

In general, behavior modeling has a decades background in educational technology: Neural and semantic networks, as well as genetic algorithms, are utilized to model a user's characteristics, profiles and patterns of behavior in order to support or challenge the performance of individuals. Behavior recording have been studied and used in the game industry for a good time. In all recent studies the level of behavior is limited, more or less, to observed patterns (e.g. Brusilovsky 2001; Houllette 2003; Bowling & al 2006; Bra & al 2013; Shyi-Ming & Po-Jui 2013).

In this study, user behavior, competence and learning is seen as Semantic (neural) network that is inductively taught by user. According to cognitive psychology of learning, our thinking is based on conceptual representations of our experiences and relations between these concepts. Phenomena when the mental structure change is called learning. The data mining and analytics are based on this semantic modeling. When all the skills and knowledge is recorded as semantic network, all the mining can be done in terms of network analysis. The novelty value of this study is in approach: to build games based technologies that enable easy inductive construction of intelligent and human like behaviors and so enables detailed analysis of learning achievements. Same kind of competence modeling, based on deductive learning theories, has been done by e.g. Biswas, Leelawong, Schwartz & Vye (2005).

Furthermore, we know that children are ready to do more work for their game characters than what they are ready to do for themselves (e.g. Chase & al. 2009). That's why we have developed games where game characters learn like humans do and children can take the role of a teacher. The framework and technology behind the games support detailed learning analytics and it provides real time analysis on learning process, difficulties in learning and challenges in curriculum.

RESEARCH PROCEDURE

In gamified environments the Zone of Proximal Development, Conceptual change and Flow can be seen as similar concepts. The aim of this study is to apply these three theories in order to build effective real-world solutions for gaming and learning industry.

The sample (N=49080) is collected with SmartKid Maths Online version, between 1.8. and 31.12.2013. This online version was targeted especially for school piloting, which helps us to make an assumption that most of the players were 1st and 2nd grade pupils. Only the players who had not completed at least 10% of the content (approximately 1.5 - 2 hours of game play on average) were included into this sample. This decision is done in order to ensure that all the included data is collected from pupils really played the game, not just tested or had a short period of use.

Because all collected data is completely anonymous, we can be sure only about the country that the data comes from. We can not guarantee that all the first grade players are really first grade pupils and so on. Furthermore, the nature of the game is that when player has completed kindergarten he/she continues to first grade. This means there are a lot of kindergarten pupils included in first grade data and a lot of first graders in second grade data. In this paper, we focus on describing the procedure and findings, so the sampling is not a problem, but when describing learning achievements and competences in details, this is maybe one of the most critical challenge to override.

In this paper, only countries with more than 1500 players were included in analysis. The final sample, 1000 pupils per country was randomly selected from all the date from the specific country. There were less than 2% differences in the results between three different random samples.

Furthermore, the sample was divided in 2 subgroups: casual players and hard gamers. Casual players were those who have completed more than 10% but less than 35% of the game. In other words those who have played 2-6 hours on average with several sessions. The hard gamers group consist of those completed more than 35% of the content. Some of them have played only 5 hours with extremely good performance, and some players have spent more than 100 hours with SmartKid Maths ending up a good performance.

However, most of the pupils who have played more than 35% of the content are kindergarten pupils who have played first grade content or first grade pupils who have played second grade content. When analyzing the results, we have to understand that what more levels player has opened, that more he/she had to face completely new topics.

In results section we have analysis from Finland, Sweden, United States, Canada, United Kingdom, Ireland, Malaysia, India, Latin America (as a group in order to reach defined n) and Australia.

RESEARCH MATERIALS

SmartKid Maths is a games based mathematics school for mobile, tablet and online users (figure 4). The biggest difference to other maths games is that in SmartKid Maths the player is teaching the computer, not vise versa. When the player is responsible for character's mental development, he/she records also his/her mental conceptual structure during the gameplay.

Figure 4. Collection of screenshots from SmartKid Maths.

SmartKid Maths include all mathematics in US common core K-2 curriculum, which represents approximately 300-400 pages exercises in traditional books. In the game, there are 100 levels and one level represents approximately one school week, 3-5 pages of exercise book, in traditional school. SmartKid Maths covers the following Common Core topics:

Grade K: Counting and Cardinality
- Know number names and the count sequence.
- Count to tell the number of objects.
- Compare numbers.

Grade 1: Operations and Algebraic Thinking
- Understand and apply properties of operations and the relationship between addition and subtraction.
- Add and subtract within 20.
- Work with addition and subtraction equations.

Grade 2: Operations and Algebraic Thinking
- Represent and solve problems involving addition and subtraction.
- Represent and solve problems involving multiplication and division.
- Add and subtract within 100.
- Multiply and divide within 100.
- Work with equal groups of objects to gain foundations for multiplication.

One of our special focuses has been scientific proof of concept: We have shown educational outcomes as well as motivation towards teaching virtual pets: Under strict laboratory experiment settings, more than 60% of players increases their skills remarkably during the gameplay. The outcome in natural learning environment with possibility to longer gameplay is even greater: In fact, we have shown that the best outcome is achieved when there are enough breaks and informal discussions between game play.

When the player is responsible for character's mental development, he/she records also his/her mental conceptual structure during the gameplay. The most important finding is that assessment done according to learning data collected during the game play correlates with assessment done with traditional paper tests: Taught conceptual structure is strongly related to paper tests score received after game play ($0.4<r<0.7$) with all tested content on mathematics and natural sciences. This is an important result in terms of reliability of the game as assessment/evaluation instrument. Because of this, we can produce detailed diagnostic information about learning (Ketamo 2009, Ketamo & Kiili 2010, Ketamo 2011).

In the Math Elements every character is an agent/entity that contains all the taught knowledge as semantic network. That semantic network can be used to produce character behaviors, including reasoning, without connection to the original game or other characters (where the knowledge is recorded). Because of every agent is taught by individual person, each agent is different is skills. Furthermore, as stated before, the knowledge and behavior recorded in agent's semantic network correlates with players real world knowledge. All this together, the agents / game characters are ideal entities to run different simulations, which can be competitions as well as complex data mining procedures.

Teaching the character can be seen in terms of Inductive learning theories. The general idea behind Inductive learning theories is that we build our understanding by processing and connecting single concepts into large conceptual understanding piece by piece. Adding new concepts or modifying the existing conceptual structure is always based on previous learning and the context of learning. Because of that, both learning and mental conceptual structures are unique for everyone.

The key elements in learning are accommodation and assimilation. In following example, assimilation describes events when a learner strengthens his/her mental conceptual structure by means of new relations (figure 5) and accommodation describes an event when a learner figures out something radically new, which leads to a change in his/her mental conceptual structure (figure 6).

When child observes (figure 5) there are animals that lives in the water, do have a tail and they are swimming, he/she starts to construct conceptual understanding on fishes. Later he/she connects animals like salmon, pike and whale into fish -category or schema. The same goes with concept of mammals, but maybe in a different way by first recognizing cat, dog, horse, etc. Later child connects them as a group with properties like breathing an air, giving a birth and breast feeding.

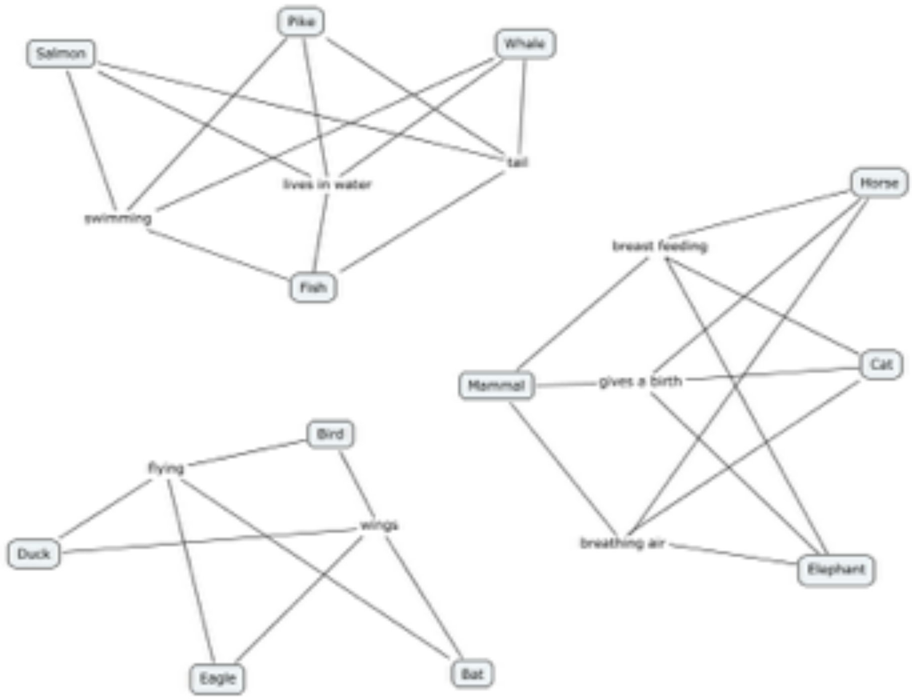

Figure 5. Conceptual learning and assimilation process while learning the animals and their classification.

When child observers e.g. that whale do have more mammal properties than fish properties (figure 6) he/she figures out that whale belongs into mammals, no fishes. This phenomena is called conceptual change. While assimilation is phenomena on adding new concepts into our existing conceptual structure, accommodation describes more radical changes in our thinking. From learning point of view both phenomenas are important, but accommodation is far more difficult to observe, record or point out of data than assimilation. That's why most of existing studies focuses only on assimilation type of learning.

Figure 6. Accommodation process and conceptual change when learning the animals and their classification.

Figure 7. Child has learned that knowledge is not black and white, there are always confusing connections in conceptual understanding.

Furthermore, after several conceptual changes and confusing observations (figure 7) child will learn that knowledge is not black and white. All our understanding is based on complex set of concepts and their relations and all concepts do have connections to several other concepts, properties and categories. Child will also learn that meaning of the concept is depending on context that concept is used. This kind of elastic conceptual structures are essential for further learning. If knowledge is learned as black and white rule based system, that blocks not only a great share of future learning opportunities but also capabilities on thinking out-of-the-box.

In SmartKid Maths, this theoretical framework is turned as game AI. The AI will learn like humans do: inductively case by case. Teaching is done in phase that consists of either a question creation and evaluation –pair or evaluation process for already known question. Each teaching phase adds new relations into the conceptual structure in the same way as described in figures 1-3. Accordingly, if the concept is not taught before, the new concept is also added into the conceptual structure during the teaching phase.

Inductive learning has been applied in Math Elements in a way where player teaches the character piece by piece in different learning contexts. While playing, the conceptual structure will grow to thousands of relations and a single teaching phase only has a limited effect on the areas of the conceptual structure already taught. Understanding this phenomenon is valuable when trying to correct a wrongly taught part of the conceptual structure. Naturally, wrong teaching could be corrected by teaching the correct structure enough times. The game AI uses all the taught information to back its decisions, and therefore it takes time to override the wrong relations in the agent's conceptual structure.

RESULTS

Analytics outcomes of learning process can be used when developing national curricula or learning materials. When summarizing the individual game achievements (taught conceptual networks), schools and national level policy makers can receive analysis about learning achievements and competences in general level. They can apply this in order to develop their teaching instructions or formal curriculum. Our goal in this paper is not to rank countries, but to provide information that might be useful for developing the curriculum or classroom practices.

In this analysis we compare differences in understanding and applying the core concepts of numeracy:

1) count of objects
2) number symbol
3) place in number line

The game records all the events during the game play. First we identify how many has faced difficulties or have recorded misconceptions during the game play. After that we analyze who have override their previous difficulties when the level or game is completed.

In left side of all the tables 1-6 are percent shares of pupils who have mastered the content all the time during the game play (less than 5% misconceptions on any stage of the gameplay) and in right side percent shares of pupils who masters the content after the level or game is completed. The difference between these shares shows the effect of the game: what bigger share of the pupils masters the content after the game play, that better the game performs as a learning game.

In tables 1-3 we focus on casual players group (completed more than 10% but less than 35% of the game). When focusing only on conceptual level, we can see that the concept of number symbol is the easiest one. In other words, pupils recognize the written numbers and only relatively small share of pupils did have challenges in applying number symbols. The number line was the most difficult concept, but surprisingly also applying counts was more challenging as the number symbols. This phenomena is the same in all the countries.

When comparing countries, there are relatively big differences in percent shares of those mastering the content. We could easily find even statistically significant differences, but because our data collection and sample definitions were relatively superficial, we do not run any statistical analysis on this sample. The idea is to describe the method and repot it's strengths and weaknesses.

Most of the differences can be explained with following two facts: 1) Kindergarten is started between 3 and 6 yeas of age, depending on country. This kind of difference in age obviously affects to performance in the game. 2) We know many kindergarten pupils played the first grade game, but we also know that in some countries we had remarkably big sample from first and second grade. When doing random sample, the big share of second graders affects the sample.

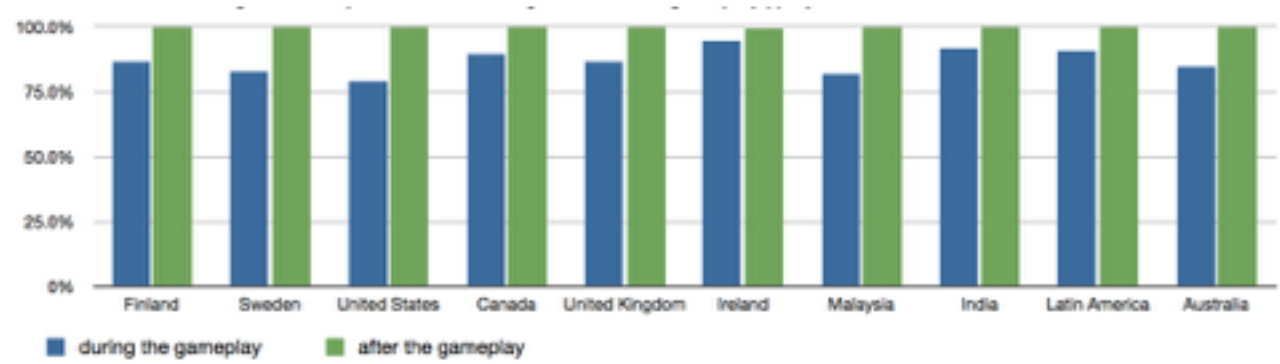

Table 1: Mastering the concept of Number (as symbol) during and after the gameplay. Players who have played more than 10% but less than 35% of content are included in figure.

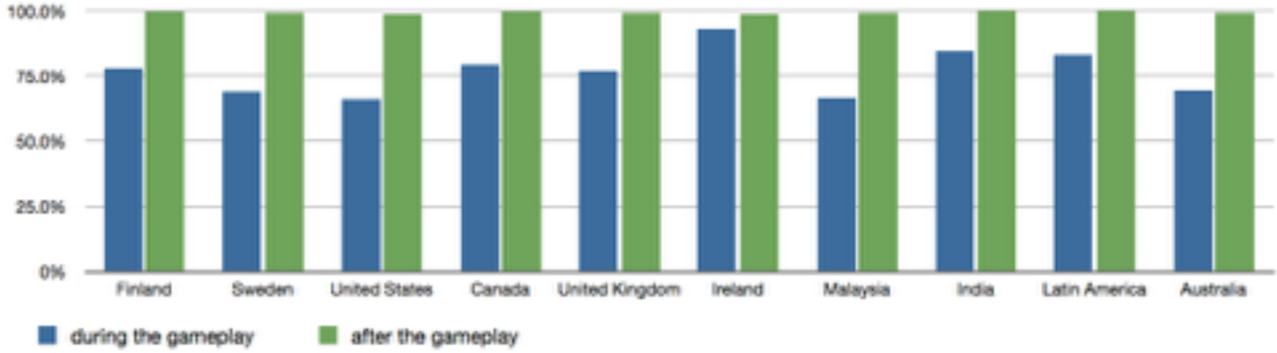

Table 2: Mastering the concept of Count during and after the gameplay. Players who have played more than 10% but less than 35% of content are included in figure.

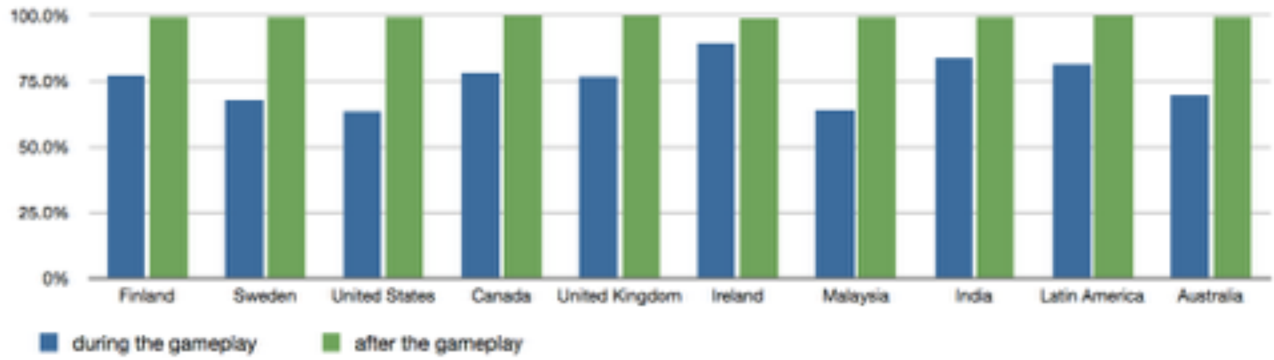

Table 3: Mastering the concept of Number Line during and after the gameplay. Players who have played more than 10% but less than 35% of content are included in figure.

In tables 4-6 we focus on hard gamers group (completed more than 35% of the content). This group is very different to casual players group: In this group most of the players have completed content (levels) that goes far beyond their school literacy. In other words, kindergarten pupil who have played half of the first grade content belongs into this group. Furthermore, is seems the those pupils who have faced challenges during the game play and override the challenges did get kind of a Flow experience on this and therefore played a longer time than those who did not learn that much new during the game play.

From tables 4-6 we can read that this time the concept of count was the easiest one. This is mostly because of the tasks in the game: Concept of count was excluded from the most difficult tasks and so the pupils could not face that big challenges with counts.

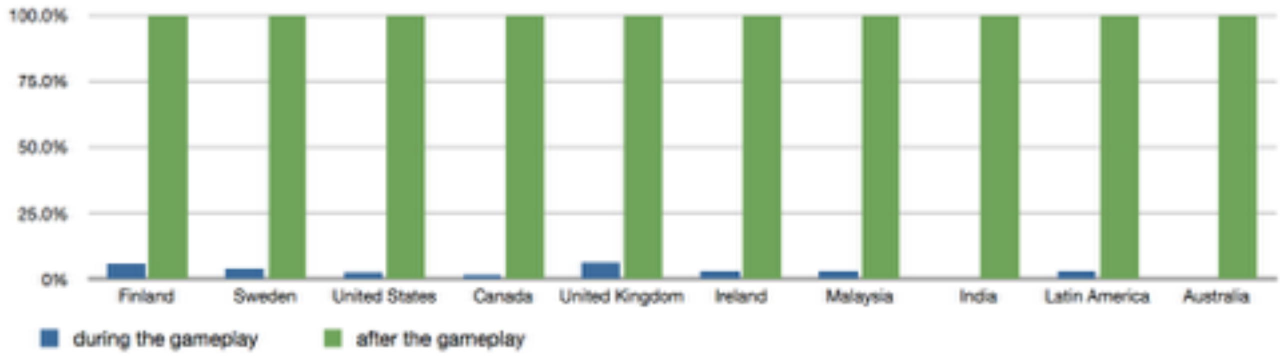

Table 4: Mastering the concept of Number during and after the gameplay. Players who have played more than 35% of content are included in figure.

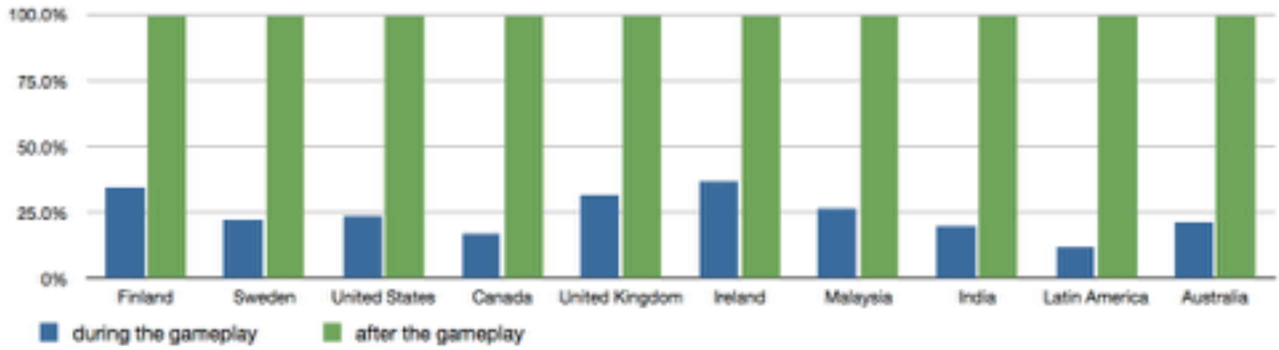

Table 5: Mastering the concept of Count during and after the gameplay. Players who have played more than 35% of content are included in figure.

Table 6: Mastering the concept of Number Line during and after the gameplay. Players who have played more than 35% of content are included in figure.

Learning is about changes in our understanding. Educational games in general are meant to provide good learning outcomes. This has been the most important goal for SmartKid Maths. When focusing on the right side of the tables 1-6 we can see that almost all of the of pupils masters the content after the gameplay, no matter how many didn't master the content before the game play.

This in not only because of the method and content. It is also because of game type of storytelling: When paying the games, kids are used to work hard in order to get the access to the next level. This goes also for SmartKid Maths. And before player could access the next level, he/she must have enough skill from previous levels. The same don't go for school, where pupils can continue with next topic no matter how many basic skills they are missing. Because SmartKid Maths is designed to provide adaptive and personalized learning, it makes sure all the basics are learned before pupil are allowed to continue. In other word, when analyzing the latest performance, almost all pupils had got the basic numeracy skills during the game play. This gives a strong background to continue addition, subtraction, multiplication and divisions.

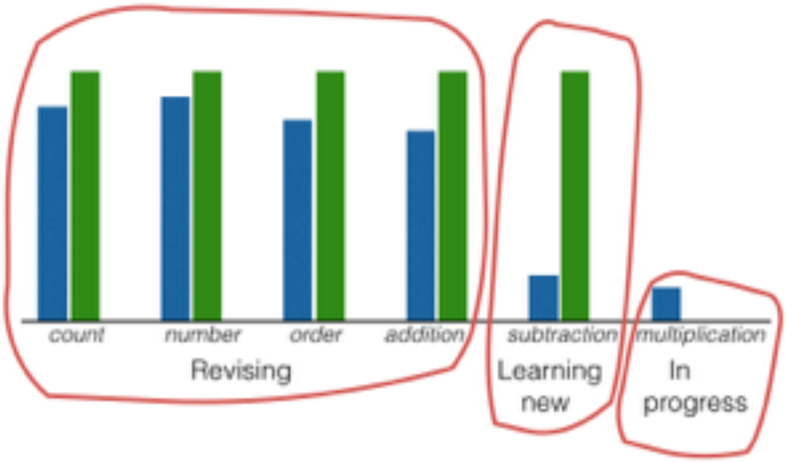

Table 7. Defining easily implementable ‘revising’, ‘learning’ and ‘new challenges’ indicators for game mechanics according to Conceptual Change and Zone of Proximal Development.

When coming back to Zone of Proximal Development and/or Conceptual Change in terms of game design, we can find a systematic pattern in game data (table 7). In table 7 each bar-set represents an archetype of level. When person already knows something, there is little change from beginning of the level to the end of the level. So we can determine, he/she is revising the topic. If player is hold too long in this mode, he/she will get bored. On the other hand, when there is a lot of change between the beginning of the level to the end of the level, the player has learned something new. In other words, we she/he found the Zone of Proximal development.

In case the level is not completed (table 7), we can determine player is either in learning -mode or maybe going to anxiety -mode. In this case, we can extend author’s old framework with this idea of revising (figure 8). If the player is moving towards revising -mode, all is ok. In case the time consumption is too high compared to improvement of players skills (required by the level), the player is in risk to fall in anxiety -mode.

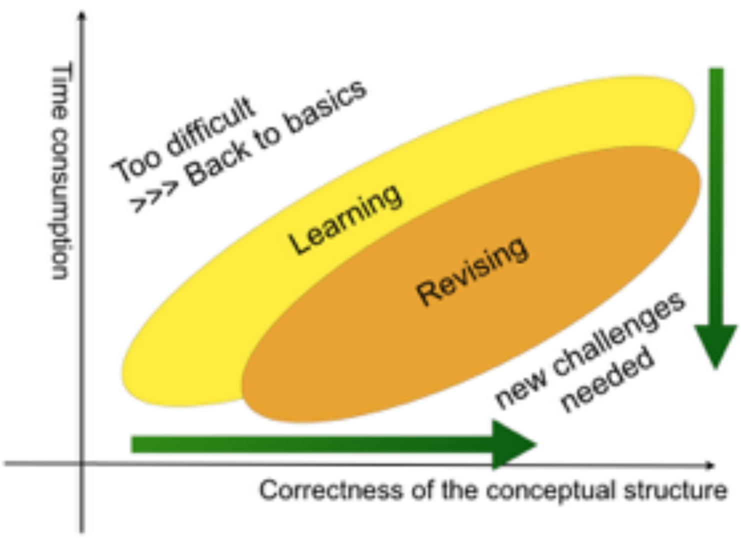

Figure 8. Determining the ‘revising’, ‘learning’ and ‘new challenges’ -modes according to time consumption and correctness of the conceptual structure (skills required before the level can be completed).

According to game data, we can say that players who have had a lot of conceptual change in their recorded playing behaviour, have played the game longer than those who did not receive such change. This result is parallel to author's previous results about the relations between conceptual change and time used to play a learning game (Ketamo & Suominen 2010). We can not say that Conceptual Change increases Flow experience or vice versa, but we can claim Flow experience is an indicator (or enabler) for learning and learning is an indicator (or enabler) for Flow.

CONCLUSIONS

Flow has been studied for decades as an enabler for learning. According to previous studies we can clearly show the similarities between theories of Conceptual Change, Zone of Proximal Development and Flow. According to results of this study, we can not say that Conceptual Change, or being in Zone of Proximal Development, increases automatically Flow experience or vice versa, but we can claim Flow experience is an indicator (or enabler) for learning and learning is an indicator (or enabler) for Flow.

The results of this study is applicable in any game related to learning new skills or competences. The exact parameters for times and shares should be measured case-by-case for this framework, but that can be done with relatively small samples and adjusted on later stage when more data is available. The most important thing from architecture point of view is that the framework for learning analytics and adaptation is valid from the very beginning.

REFERENCES

Biswas, G., Leelawong, K., Schwartz, D., Vye, N. (2005). Learning by Teaching: A New Agent Paradigm for Educational Software. Applied Artificial Intelligence, 19 (3-4), 363–392.

Bowling, M., Furnkranz, J., Graepel, T. & Musick, R. (2006). Machine learning and games. Machine Learning, vol 63, pp. 211-215.

Bra, P., Smits, D., Sluijs, K., Cristea, A., Foss, J., Glahn, C. & Steiner, C.M. (2013). GRAPPLE: Learning Management Systems Meet Adaptive Learning Environments. In Peña-Ayala, A. (ed.) Intelligent and Adaptive Educational-Learning Systems: Smart Innovation, Systems and Technologies. Volume 17, 2013, pp 133-160.

Brusilovsky, P. (2001). Adaptive Hypermedia. User Modeling and User- Adapted Interaction, vol 11, p. 87-110.

Csikszentmihalyi, M., (1991). Flow: The Psychology of Optimal Experience. New York: Harper Perennial.

Chase, C, Chin, D, Oppezzo, M, Schwartz, DL. (2009). Teachable agents and the protege effect: Increasing the effort towards learning. Journal of Science Education and Technology, 18, 334-352.

Deterding, S., Sicart, M., Nacke, L., O'Hara, K. & Dixon, D. (2011). Gamification. Using game-design elements in non-gaming contexts. In CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11). ACM, New York, NY, USA, pp. 2425-2428.

Deterding, S., Björk, S., Nacke, L., Dixon, D. & Lawley, E. (2013). Designing gamification: creating gameful and playful experiences. In CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13). ACM, New York, NY, USA, pp. 3263-3266.

Groh, F. (2012). Gamification: State of the Art Definition and Utilization. In pp. 39-46.

Hakulinen, L. & Auvinen, T. (2014). The Effect of Gamification on Students with Different Achievement Goal Orientations. In Proceedings of the 2014 International Conference on Teaching and Learning in Computing and Engineering (LaTiCE '14), Kuching, Malaysia, pp. 9–16.

Hense, J., Klevers, M., Sailer, M., Horenburg, T., Mandl, H. & Günthner, W. (2014). Using Gamification to Enhance Staff Motivation in Logistics. In Frontiers in Gaming Simulation. Lecture Notes in Computer Science Volume 8264, 2014, pp. 206-213.

Houlette, R. (2003) Player Modeling for Adaptive Games. In Rabin, S. (ed.) AI Game Programming Wisdom II. Massachusetts: Charles River Media, Inc.

Hutchinsona, J.C. & Tenenbaumb, G. (2007). Attention focus during physical effort: The mediating role of task intensity, Psychology of Sport and Exercise, 8(2), 233-245.

Ketamo, H. (2003). An Adaptive Geometry Game for Handheld Devices. Educational Technology & Society journal, vol 6(1), pp. 83-95. [onLine: http://www.ifets.info/journals/6_1/ketamo.pdf].

Ketamo, H. & Multisilta, J. (2003). Towards Adaptive Learning Materials: Speed of interaction and relative number of mistakes as indicators of learning results. Education and Information Technologies, vol 8(1), 55-66.

Ketamo, H. (2009). Semantic networks -based teachable agents in an educational game. Transactions on Computers, vol 8(4), pp. 641-650.

Ketamo, H. & Kiili, K. (2010). Conceptual change takes time: Game based learning cannot be only supplementary amusement. Journal of Educational Multimedia and Hypermedia, vol. 19(4), pp. 399-419.

Ketamo, H. & Suominen, M. (2010). Learning-by-Teaching in an Educational Game: The Educational Outcome, User Experience and Social Networks. Journal of Interactive Learning Research, vol. 21(1), pp. 75-94.

Ketamo, H. (2011). Sharing Behaviors in Games and Social Media. International Journal of Applied Mathematics and Informatics, vol. 5(1), pp. 224-232.

Ketamo, H. (2013). Learning Analytics with Games Based Learning. In proceedings of the 7th European Conference on Games Based Learning. 3-4 October, Porto, Portugal, pp. 284-289.

Kiili, K. (2005). Digital Game-based Learning: Towards an Experiential Gaming Model. The Internet and Higher Education, 8(1), 13-24.

Kiili, K. & Ketamo, H. (2007). Exploring the Learning Mechanism in Educational Games. Journal of Computing and Information Technology, 15(4), 319-324.

Kiili, K. (2007). Foundation for Problem-Based Gaming. British Journal of Educational Technology – Special issue on Game-Based Learning, 38(3), 394-404.

Kiili, K., Ketamo, H., Koivisto, A. & Finn, E. (2014). Studying the user experience of a tablet based math game. In International Journal of Game-Based Learning, vol. 4(1), pp. 60-77.

Kiili, K., Ketamo, H. & Kickmeier-Rust, M.D. (2014). Eye Tracking in Game-based Learning Research and Game Design. In International Journal of Serious Games, vol. 1(2), pp. 51-65.

Kumar, J. (2013). Gamification at Work: Designing Engaging Business Software. In Design, User Experience, and Usability. Health, Learning, Playing, Cultural, and Cross-Cultural User Experience. Lecture Notes in Computer Science Volume 8013, 2013, pp. 528-537.

Mayer, R. (2004) Should there be a three-strikes rule against pure discovery learning? American Psychologist, Vol 59, pp. 14-19.

McCallum, S. (2012). Gamification and Serious Games for Personalized Helath. In Blobel, B., Pharow, P., Sousa, F. (eds.) PHealth 2012: Proceedings of the 9th International Conference on Wearable Micro and Naono Technologies for Personalized Health. IOS Press, Amsterdam, The Netherlands, pp. 85-96.

Shyi-Ming, C. & Po-Jui, S. (2013). Constructing concept maps for adaptive learning systems based on data mining techniques. Expert Systems with Applications. Volume 40 (7), pp. 2746–2755.

Sinclair, J., Hingston, P., & Masek, M (2007). Considerations for the design of exergames. In proceedings of GRAPHITE 2007, Perth, Australia, 289–295.

Tenenbaum G., (2001). A social-cognitive perspective of perceived exertion and exertion tolerance. In: R.N. Singer, H. Hausenblas and C. Janelle, Editors, Handbook of sport psychology, Wiley, New York (2001), pp. 810–820.

Tenenbaumb, G. & Connollya, T.C (2008). Attention allocation under varied workload and effort perception in rowers. Psychology of Sport and Exercise, 9(5), 704-717.

Stafylidou, S. & Vosniadou, S. (2004) Students' understanding of the numerical value of fractions. Learning and Instruction, Vol 14, pp. 503–518.

Vosniadou, S. (2007) Conceptual change approach and its re-framing. In Vosniadou, S., Baltas, A. & Vamvakoussi, X., (Eds), Re-Framing the Conceptual Change Approach in Learning and Instruction. Advances in Learning and Instruction Series, Oxford: Elsevier Press, pp. 1-15.

Vosniadou, S. & Verschaffel, L. (2004) Extending the conceptual change approach to mathematics learning and teaching. Learning and Instruction, Vol 14, pp. 445-451.

Vygotsky, L.S. (1962). Thought and Learning. Cambridge, Massachusettes. The M.I.T. Press.

Vygotsky, L.S. (1978). Mind and society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.