A Three-Dimensional Model for Educational Game Analysis & Design

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ABSTRACT
For over thirty years, there has been a discussion about the effectiveness of educational games in comparison to traditional learning materials. To help further this discussion, we aim to understand 'how educational games work' by formalising (and visualising) the educational and motivational aspects of such games. We present a model that focuses on the relationship between three different aspects: user properties, game mechanics, and learning objectives. In two example cases, we have demonstrated how the model can be used to analyse existing games and their game/instructional design, and suggest possible improvements in both motivational and educational aspects based on the model. As such, we introduce a novel approach to analysing educational games and, by inference, a novel design process for designing more effective educational games.

Categories and Subject Descriptors
Applied Computing [Computers in other domains]: Personal computers and PC applications—Computer games.

General Terms
Design.

Keywords
Educational Game Design, Design Research, and Model-Driven Approaches.

1. INTRODUCTION
For over thirty years researchers have been trying to determine how effective educational games are in comparison to traditional learning materials, such as books and lectures. While some work shows that games can be significantly more effective and motivating, other work does not find the same kind of results [1].

The reason for these different findings may be because it is not yet clear in what manner an educational game should be designed to ensure optimal learning. One thing is certain: a serious game can only be truly effective if it is both engaging and instructional [2]. An important question is thus, what do we need to ensure that game design and education fit together in a single cohesive unit? It seems likely that educational goals should somehow be integrated into the core gameplay [3, 4], but there are, unfortunately, few concrete guidelines for how to do so.

Fisch [5] is a fond believer in the educational value of serious games. He argues that for a game to be educationally effective, its educational goals and gameplay should go hand in hand. He gives an example of a game used to increase health and hygiene in children currently attending preschool. In this game, players have to find two similar cards in a set of cards that are face down; each of the cards features a figure related to health and hygiene. Fisch argues that because the gameplay and the educational content are separated in this game, the educational impact of the game is quite low.

Recently there have been researchers exploring the idea of creating games in which the learning objectives are integrated into the core game design. For example, Hall, Wyeth and Johnson [6] have created a series of questions based on integral parts of core gameplay to aid designers in formalizing the core gameplay and learning components of an educational game. Echeverría et al. [7] show that a redesign of the game to align gameplay and educational content may lead to more effective educational games.

The weaving of gameplay and educational content seems promising, but many researchers tend to focus on the end results, i.e. does the game work, instead of how games can be designed to facilitate learning [8]. In other words, there is a lot of focus for determining 'if it works', and little focus for determining 'how it works'.

Dondlinger argues that researchers should aim to create more clear design choices for educational games [8]. By doing so, the design process becomes more clear and transparent and leads to the design of more effective games. To ensure that these design choices are generalizable, we need to take a design research perspective, and define a language that can be used to describe the design choices in a universal manner. Eventually, this may lead to a set of game design patterns that specifically focus on the integration of gameplay and educational content. In this paper, we will take the first steps in this process. We will present our model on the effective design of educational games, present a way to analyse and formalize educational games through two case studies, and end with some conclusions and recommendations for future research.

2. THE WAY FORWARD

We propose using a model that is comprised of three different elements: user properties, game mechanics, and learning objectives. These aspects are important to consider in the design of an educational game, but even more important is their relationship to each other (see Figure 1).

2.1 User vs. Learning

This dimension is concerned with the discrepancy between the learning objectives and the user properties. If the distance between these two is too great, then it will be difficult for the user to acquire new skills or knowledge from the learning content. This is a common problem in games where there is either little feedback or support for the user to learn without supervision.

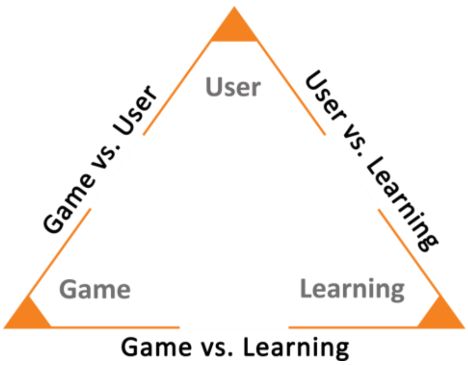

Figure 1: Three Dimensions of Effective Educational Game Design

An important part of this dimension is the feedback that is provided to the user. Feedback has been proven to be quintessential to learning, but only if it is the right kind and given at the right time [9]. Some researchers try to circumvent this problem, for example through the use of a 'hint' button that can be activated whenever the user feels they need help, but this may only make users 'give up early' or abuse it in other ways [10].

Another important aspect is the way in which the feedback is delivered [11]. If it is too abstract, the user will have difficulty tying the knowledge or skills acquired in the game to a real world context. To create a (permanent) change in mental models, users need to be able to reflect on their actions. This can be done by having a moment of reflection between gaming sessions, or after the game, when the user has had more time to think about the subject matter.

Even more important is to ensure that the feedback and the content of the educational topics 'fit' the mental model of the user. A game could include for instance a 'trial-and-error' type of gameplay, but if the user does not understand the 'trials', feedback will have little effect. This lack of knowledge or skills can also occur throughout the game, if the learning content becomes too difficult for the user. It is important that the user is able to stay in the zone of proximal development, which can be achieved by applying scaffolding [12, 13, 14]. This way, the game would prevent itself from being too easy or too difficult for the user to progress.

2.2 Game vs. User

This dimension is concerned with the discrepancy between the game mechanics and the user properties. If the distance between these two is too great, then the user will not be motivated or interested by the game. This is a common problem for edu-games, in which the entertainment aspects are usually neglected, or games used outside of their niche target audience.

Too often it has been the case that users perform worse after playing an educational game or do not find the experience engaging due to boredom or bad game design [15, 10]. As such, 'motivation' has been the focus of attention for a long time; there are many papers and reviews on different aspects of motivation in games [16, 17].

One of the strengths of a game can be to make an otherwise boring or hard subject enjoyable. Abstract theories or concepts can be presented in an interactive and accessible manner [19], motivating the user to explore these topics in an experiential way.

An aspect strongly tied to engagement is the balance between a user's current skills and the difficulty of the challenges offered by the game. According to the theory of flow [18], a game that is too easy or too difficult quickly loses the player's interest, either through boredom or frustration. However, in the design of educational games we must integrate the required level of the learning objectives with a suitable level of challenge for the player.

2.3 Game vs. Learning

This dimension is concerned with the discrepancy between the game mechanics and the learning objectives. If the learning objectives are not properly integrated in the core mechanics, it is likely that there is a limited transfer of the learning objective. This is a common problem in games in which the learning components are tacked on; the actions of the users are completely unrelated to the learning objectives.

In the past decade, the body of research on educational games has grown, but has not yet fully matured [20]. For the field to mature, it is important that we try to understanding why games work; what are the components of educational games that help increase motivation and learner performance? One of the core concepts of this approach is the alignment of core gameplay with the educational goals. This alignment has proven itself by increasing enjoyment as well as learning effectiveness in games [12, 7].

The question this design approach raises is: '*What should the connection be between the core gameplay and the learning objectives?'* Being aware of this connection help the designer to ensure that the actions of the user align to what the game is trying to teach. Doing so makes it easier to strike the balance between learning and enjoyment and prevents flow from being interrupted. Several frameworks have been developed to aid designers in creating such educationally-aligned games [21, 6].

Having this integration between learning objectives and game mechanics also makes it easier to design for school curricula, which in turn helps teachers to know how to use the game in their classroom. Early research shows that curriculum-based educational games can lead to a better number sense for children [22].

2.4 Conclusion

To ensure an effective educational game, we need to…

- … explicitly formalise the learning objectives and the process in which users acquire new knowledge or skills;
- … explicitly formalise the core game mechanics;
- … explicitly formalise the capabilities of the user.

By creating a flowchart that incorporates these three elements, we can increase our understanding of how a particular educational game works and how these elements are related. As a consequence, we gain insights into how the game should be redesigned to create a more effective educational game. Applying this approach to a larger set of educational games may reveal particular game design patterns for educational games that provide concrete design guidelines.

3. GAME ANALYSES

In this chapter, we will look at two games that attempt have integrated similar learning objectives, but have used different game mechanics. For both games, we will analyse the core mechanics and learning objectives, and the way it supports skill and knowledge acquisition in the user.

3.1 Game Analysis 1 – Grand Prix Multiplication

Grand Prix Multiplication[1] is a competitive math game in which multiple players compete against each other in a Grand Prix-like race (see Figure 2). Players can join in an online game that starts as soon as all players are ready to go.

Figure 2: Screenshot of the Grand Prix Multiplication educational game

3.1.1 Core Mechanics & Learning Objectives

Each player has to solve multiplication questions individually and, by giving the right answer, receive an increase in driving speed (and vice-versa). They do not have to manually steer the car, so they only have to worry about answering the questions. The quicker the user, the more questions he or she can complete, and thus the faster he or she can complete the lap. The first player to reach the finish wins the game.

The core game mechanic of the game is thus a reward (speed increase) based upon the validity of the answer on a multiplication question. The game presents a series of multiple choice questions about multiplication until the end of the race.

[1] http://www.arcademics.com/games/grand_prix/grand_prix.html

The learning objective of the game Grand Prix Multiplication is to increase automaticity in multiplication facts from 1 to 12, which accommodates the common core standards for grade 3 in operations and algebraic thinking. As such, the game is primarily designed for users who are attending the third grade of primary school.

The developers of the game claim that their games "improve student performance through:

- Increased time on task;
- Increased student motivation and engagement;
- Increased corrective feedback."

3.1.2 Skill and Knowledge Acquisition

To analyse how the game supports learning, we identified the relevant steps in the core gameplay loop. We distinguish between the actions performed by the system, those performed by the user, and the expected reflection and cognition taking place within the user. A flowchart of this process for Grand Prix Multiplication is shown in Figure 3.

The game tries to teach the user multiplication through drill-and-practice. Upon making an error, the game presents the user with the correct answer for a short amount of time, giving him/her a moment to internalize the right answer. This moment, along with the general cognitive effort required to answer the multiple choice questions, comprises the process which should lead to an increase in automaticity.

3.1.3 Conclusion

Although the game uses an accepted method to achieve the learning objective, drill and practice, the educational game design helps to determine some underlying issues:

1. Motivation through competition with classroom peers does not necessarily lead to better learner performance [23];
2. No connection is made between the gameplay and the learning objective;

The lack of a connection between the gameplay and the learning objective hampers the effectiveness of this game. Answering the multiplication questions has no relevance for the racing part other than determining how fast the car will go. The whole racing aspect could be removed by a simple score tracking, and the flow of the game would remain the same. Simply focussing on the questions while not looking at what your position in the race would lead to better results, as there is less unnecessary strain on your working memory [24].

3. Multiplication has to be practiced through multiple choice questions. However, this does not necessarily lead to deep learning [24];
4. The feedback is corrective, which does not help the user understand his or her errors.

Due to the nature of the game, it is also much harder to provide useful feedback. While explanatory feedback on wrong multiplication strategies would lead to better learning, the corrective feedback used here is the only viable option to keep the gameplay as is. Whether this twitch-like gameplay is actually the right choice for this learning objective is a different story, requiring additional research.

While the game supports practicing multiplication with feedback, it doesn't necessarily teach its users how to do this. As such it implicitly expects the user to be familiar with basic rules of

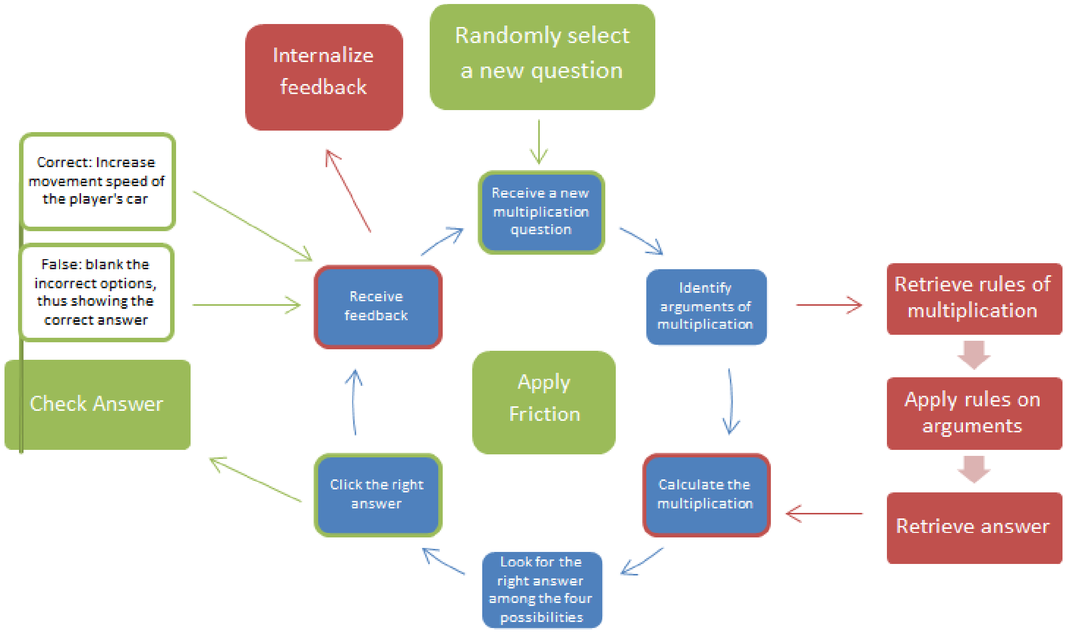

Figure 3: An analysis of Grand-Prix Multiplication on three levels: actions performed by the system (green), actions performed by the user (blue), and reflection and cognition in the user (red).

multiplication, defeating part of the intended learning objective beforehand. The limited effect of drill-and-practice designs in educational games was pointed out before by Squire [25].

In conclusion, we can directly relate these findings to the three dimensions of our proposed model:

- User vs. learning: the feedback provided is corrective and the user is distracted by the gameplay;
- Game vs. learning: the learning objectives are unrelated to the gameplay;
- Game vs. user: the game assumes pre-play familiarity with multiplication rules.

3.2 Game Analysis 2 – Zombie Division

Habgood et al.'s Zombie Division [12] is a single player adventure game focused on divisor recognition and number sense in mathematics. It uses a fantasy setting of ancient Greece, where the player has to put the souls of athletes to rest by defeating their skeletons (see Figure 4).

3.2.1 Core Mechanics & Learning Objectives

The user is given weapons which are represented by icons of actual weapons, but are accompanied by a number (ranging from 2 to 10). Each skeleton has a number on its chest. A skeleton can be defeated by striking it with the right weapon. The correct weapon can be determined based on the number on the skeleton's chest and the number of the weapon. The weapon's number has to be a legal divisor for the number of the skeleton (e.g. 14 can be divided by either 2 or 7).

The player receives three weapons at the start of each dungeon and has to explore it to find and defeat all of the skeletons. The final skeleton will drop a key with which the player can proceed to the next level.

Zombie Division aims to teach the user the relationship between the multiplication tables and division as well as identifying legal divisors for numbers. The game requires a basic level of knowledge of the multiplication tables and being able to apply division, but is mostly for advancing and automatizing the mental strategies for solving division problems.

Figure 4: Screenshot of the Zombie Division educational game

3.2.2 Skill and Knowledge Acquisition

Again, we identified important steps in the user's interaction with this game. This flowchart depicting the core flow of the game is shown in Figure 5.

Feedback is given by showing the quotients of the division in the form of little ghosts appearing from the slain skeleton. The player is also accompanied by a pedagogical character named 'Gargle', which gives just-in-time instructions and help when the player is stuck or experiencing other problems. The feedback that the character gives to the user is not highlighted in their work.

They included scaffolding by using more difficult numbers and by introducing stronger skeletons later on in the game. These stronger skeletons either had a weapon of their own, with which

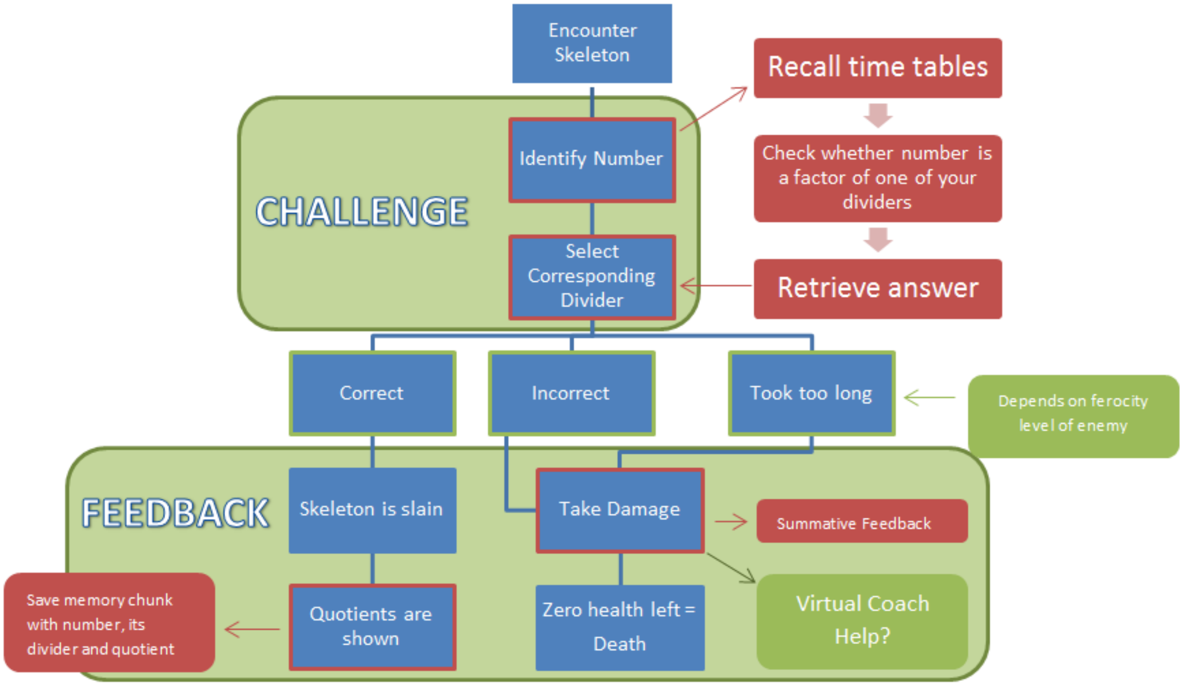

Figure 5: An analysis of Zombie Division on three levels: actions performed by the system (green), actions performed by the user (blue), and reflection and cognition in the user (red).

they could parry certain attacks (e.g. a skeleton with a shield blocking the attack with the number 2) or were larger and the resulting quotients had to be lower than 10. These two features were added to make sure that the player would use a broader repertoire of divisors, instead of dividing all even numbers by two, for example.

3.2.3 Conclusion

Habgood et al. developed this game to better understand how the gameplay should be aligned with the learning objectives. They made two versions: one in which the educational activity largely overlapped with the core gameplay and another in which the two were separated. They found that the integration led to increased learner performance and motivation.

A particularly important part of their method involved conducting reflection sessions with the players in between game sessions. During this session, the children had to discuss their experiences with the game. This process helped the students to achieve the necessary deep learning to better understand the performed tasks.

Although this game is essentially a drill & practice game (each level consists of the same challenge but increased difficulty and time pressure), it is quite different than the other game discussed in this work.

One could argue that this game also offers distracting features, e.g. having to explore a vibrant maze-like world. However, the difference with Grand-Prix Multiplication is that Zombie Division uses these things in alignment with the learning objective instead of as a motivational hook. It gives the player more agency and makes the tasks he or she has to do more relevant. Whereas the racing aspect of the previous game was just there to maintain the players' motivation, it did not have any connection with doing the multiplications.

- User vs. learning: reflective feedback, scaffolding, and contextual help (virtual coach) are provided to support the user;
- Game vs. learning: the gameplay is strongly tied to the learning objectives through both the visual representation and the mechanics;
- Game vs. user: the abstract topic of calculation is presented in an interesting environment and users of various skill levels are supported in play.

4. CONCLUSION

We have introduced and motivated a model of educational game design that features three dimensions: user vs. learning, game vs. user, and game vs. learning. Along these dimensions, we can detect discrepancies in the design of educational games, and find possibilities to improve the alignment of the learning objectives with the gameplay as well as their relation to the users' expectations, interest, and knowledge. In two example cases, we have demonstrated how the model can be used to analyse existing games and their game design. In one case we found that the game mechanics and the learning objectives were disconnected, and with the other we found a good overlap. As such, we introduce a novel approach to analysing educational games and, by inference, a novel design process for designing more effective educational games.

The dimensions presented in this model are defined at a relatively abstract level: they revolve around the three core elements involved (game, user, and learning). Additional research is required to determine which aspects can be identified to explain and remedy the discrepancies found. Some existing work provides useful indications that fit into our approach, for example, work related to the alignment of story/fantasy with the game mechanics [26].

In the process of analysing the two example cases, we used a rough graphical notation of important processes and steps in the game, pertaining to the expected user actions, programmed system actions, and core gameplay loops. This method of analysis allowed for a deeper insight into how the game works as a learning tool, and supports comparison of the learning method as it is embedded within the game to similar learning methods that do not use a game. An area of future study is the formalisation of the approach and notation in analysing such games. This is closely connected to determining the underlying aspects of each dimensions, and the two topics may very well go hand in hand.

In the discussion of the model and the analyses, we have focused largely on the game vs. learning dimension. This concerns the integration and alignment of the game mechanics with the learning objectives. We believe this may be the most salient dimension for improving educational game design, as it represents the core of what educational games are about. The dimension of user vs. learning, while important for educational game design, is largely in the domain of instructional design, whereas the dimension of game vs. user is largely in the domain of game design in general. Nevertheless, our future work will focus on exploring this model in all three dimensions.

We present this model as a first draft of how we can work towards an improved process of designing educational games. As we have seen that, in some cases and circumstances, educational games may offer many benefits to learners and teachers, we are seeking to understand how to increase their effectiveness.

5. REFERENCES

[1] Papastergiou, M. (2009). Exploring the potential of computer and video games for health and physical education: A literature review. Computers & Education, 53(3), 603–622. doi:10.1016/j.compedu.2009.04.001

[2] Eck, R. van. (2006). Digital Game-Based Learning : It's Not Just the Digital Natives Who Are Restless …. Educause, 41(2).

[3] O'Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: evidence from the computer games literature. The Curriculum Journal, 16(4), 455–474. doi:10.1080/09585170500384529

[4] Gee, J.P. (2004). Learning by design: Games as learning machines. Interactive Educational Multimedia, No. 8, pp. 15-23.

[5] Fisch, S. M. (2005). Making educational computer games educational. In Proceedings of the 2005 conference on Interaction design and children (pp. 56-61). ACM.

[6] Hall, J. V., Wyeth, P. A., & Johnson, D. (2014). Instructional objectives to core-gameplay: a serious game design technique. In Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play (pp. 121-130). ACM.

[7] Echeverría, A., Barrios, E., Nussbaum, M., Améstica, M., & Leclerc, S. (2012). The atomic intrinsic integration approach: A structured methodology for the design of games for the conceptual understanding of physics. Computers & Education, 59(2), 806-816.

[8] Dondlinger, M. J. (2007). Educational Video Game Design : A Review of the Literature. Journal of Applied Educational Technology, 4(1), 21–31.

[9] Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. Computers & Education, 67, 156-167.

[10] Ke, F. (2008). A case study of computer gaming for math: Engaged learning from gameplay? Computers & Education, 51(4), 1609-1620.

[11] Shute, V. J. (2008). Focus on formative feedback. Review of educational research, 78(1), 153-189.

[12] Habgood, M. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. The Journal of the Learning Sciences, 20(2), 169-206.

[13] Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. Computers & Education, 70, 65-79.

[14] Chen, C. H., & Law, V. (2015). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. Computers in Human Behavior.

[15] Christensen, C. A., & Gerber, M. M. (1990). Effectiveness of computerized drill and practice games in teaching basic math facts. Exceptionality: A Special Education Journal, 1(3), 149-165.

[16] Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. Internet and Higher Education, 8, 13–24. doi:10.1016/j.iheduc.2004.12.001

[17] Paras, B., & Bizzocchi, J. (2005). Game, motivation, and effective learning: An integrated model for educational game design. In Proc. 1st Int. Conference of the Digital Games Research Association. Retrieved from http://summit.sfu.ca/item/281

[18] Chen, J. (2007). Flow in games (and everything else). Communications of the ACM, 50(4), 31-34.

[19] Clark, D. B., Nelson, B. C., Chang, H. Y., Martinez-Garza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring Newtonian mechanics in a conceptually-integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States. Computers & Education, 57(3), 2178-2195.

[20] Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B. & Yukhymenko, M. (2012). Our princess is in another castle a review of trends in serious gaming for education. Review of Educational Research, 82(1), 61-89.

[21] Shelton, B. E., & Scoresby, J. (2011). Aligning game activity with educational goals: following a constrained design approach to instructional computer games. Educational Technology Research and Development, 59(1), 113-138.

[22] Schenke, K., Rutherford, T., & Farkas, G. (2014). Alignment of game design features and state mathematics standards: Do results reflect intentions? Computers & Education, 76, 215-224.

[23] Lam, Shui-Fong, et al. "The effects of competition on achievement motivation in Chinese classrooms." British Journal of Educational Psychology 74.2 (2004): 281-296.

[24] Clark, R. C., & Mayer, R. E. (2011). E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning. John Wiley & Sons.

[25] Squire, K. "Video games in education." International Journal of Intelligent Games & Simulation 2.1 (2003): 49-62.

[26] Gunter, Glenda A., Robert F. Kenny, and Erik H. Vick. "Taking educational games seriously: using the RETAIN model to design endogenous fantasy into standalone educational games." Educational Technology Research and Development 56.5-6 (2008): 511-537