DIGITAL GAMING FOR EVOLUTIONARY BIOLOGY LEARNING: THE CASE STUDY OF PARASITE RACE, AN AUGMENTED REALITY LOCATION-BASED GAME

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Abstract Games have been used for a long time in teaching and learning. The increasing use of mobile phones makes it possible to link learning outside the classroom with augmented reality (AR). We tested how well the learning of conceptual models can be facilitated by AR games. We present a game designed for the in-service teacher-training workshop to model evolutionary and ecological relationships explicitly. The game, Parasite Race, models the life cycles of three different parasites and allows player to choose between two evolutionary strategies. We tested the game with experienced teachers and revealed a wide range of different gaming strategies: some of the teachers were able to reflect their game strategy and choose appropriate actions right away whereas some of the teachers did not and lost their motivation quickly. We reflect on the experience of programming a simple AR location-based game and on the usability of simple games in the educational context.

Keywords conceptual model, augmented reality, digital gaming strategies, evolutionary biology learning, teacher education

DIGITAALISET PELIT EVOLUUTIOBIOLOGIAN OPETUKSESSA: TAPAUSTUTKIMUS PARASIITTIEN KILPAILUSTA, PELISTÄ JOSSA ON PAIKKAAN PERUSTUVA LISÄTTY TODELLISUUS

Tiivistelmä Pelejä on käytetty pitkään opetuksen ja oppimisen tukena. Yhä lisääntyvä kannettavien laitteiden käyttö tekee mahdolliseksi yhdistää lisätyn todellisuuden luokkahuoneen ulkopuoliseen oppimiseen. Tutkimme kuinka hyvin käsitteellisten mallien oppimista voidaan helpottaa lisätyn todellisuuden pelien avulla. Esittelemme ekologisia ja evoluutiobiologisia suhteita eksplisiittisesti mallintavan pelin, joka suunniteltiin opettajien täydennyskoulutusta varten. Peli, Loisintaa Kumpulassa, mallintaa kolmen eri loisen elinkiertoja ja kahdenlaista erilaista evolutiivista strategiaa. Peluutimme peliä kokeneilla opettajilla ja löysimme laajan valikoiman erilaisia pelistrategioita. Osa opettajista pystyi nopeasti reflektoimaan pelistrategiaansa ja toimimaan pelissä tehokkaasti, kun taas osa opettajista ei tehnyt näin ja menetti motivaationsa nopeasti. Pohdimme lisäksi yksinkertaisen lisätyn todellisuuden pelin ohjelmointikokemusta ja yksinkertaisten pelien hyötyjä opetuksessa.

1 Introduction

Games are an old and widely used method of teaching (Granic, Lobel, & Engels, 2014). Especially in primary school, games and play are used as tools to understand basic concepts and models. Board games and digital games are also widely used in secondary and higher education. In recent years, gamification has become an important strategy for training and teaching, especially in fostering creative thinking (Kapp, 2012; see Table 1 for definitions). There is a wide market for educational games, and due to progress in entertainment technology and the ever-increasing success of computer games, the use of commercial off-the-shelf (COTS) games for educational purposes has also been suggested (Table 1).

The gaming landscape has changed drastically with an increase in the diversity of games partly due to the rise in mobile phone gaming. Gaming is no longer geared specifically to "power gamers". The most important change though is that games do not need to use expensive 3D graphics to be highly engaging (Klopfer et al., 2009): "casual games", like mobile games Angry Birds or Clash of Clans, are simple and easy-to-learn. These games can be a powerful model for educational games. Still, there has been a lack of unifying theoretical frameworks for educational games (Gredler, 1996; Starks, 2014). Furthermore, while there has been a distinct lack of proof either way for the speculated "greater engagement" that these games might provide, there is active research on different games (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Squire, 2006). There is little evidence of formal learning as there are few studies done explicitly in the classroom setting, probably due to the difficulties of setting the games in curricular context (Connolly et al., 2012). It is also possible that the attractiveness of computer gaming does not translate to educational games as the resources used in making educational games are only a small fraction of those commercial games, leading to a much less attractive gaming experience (Buckingham, 2007).

Table 1. The main gaming terms used in this article are defined here based mostly on Nousiainen (2013a) except for augmented reality, which is defined based on Milgram & Kishino (1994) and COTS game, which is based on Charsky & Mims (2008)

Game	A rule-based formal system which has a variable and measurable final results, with final results having different values from the point of view of players
Commercial off-the-self (COTS) game	A game created almost entirely for entertainment purposes for commercial sale and creating profit for the game designer and producer
Learning game	A game with clear didactic objective and which can be used to support learning processes in formal, non-formal or informal setting by creating immersive learning experiences
Serious games	Games with the main function of learning, rather than entertainment

Gamification	Using elements typical to games (challenges, levels, points) in different contexts like marketing, research and development and also increasingly in education
Location-based gaming	Games that are based on physical locations that players need to move to.
Augmented reality	A real-world environment whose elements are supplemented by computer-generated input, like sounds, video or graphics

We were interested in studying how computer games can simulate complex scientific models in learning of biology. Many students have regularly problems to grasp and understand conceptual models (e.g., genes; Gericke, 2008; Aivelo & Uitto, 2014). Thus computer simulations that encode relevant biological phenomena can also be helpful in learning complex phenomena with model-based reasoning. A conceptual model includes concepts that are necessary for a person to understand the phenomena represented by the conceptual model. The characteristics of the conceptual models depend on the phenomena as well as the viewpoint of the observers and their intent to represent their understanding of the system under study (Nercessian, 2008). Conceptual models are essential in learning of biology. For instance, “species”,” gene” and “DNA” are biological concepts as well as processes between the objects. Many biological phenomena are broad and abstract but can be described by a single concept, such as competition, parasitism or symbiosis in population biology, or adaptation in evolutionary biology. Concepts can be described using verbal, visual, mathematical, dynamic or physical conceptual models (Koba & Tweed, 2009).

Our aim was to explore how well gaming could be used to give concrete example of the concept of scientific models by building our own model of parasite lifecycles. We built a new augmented reality game relating to the parasite life cycles and tested how well the game functioned by observing teachers participating in workshops and recording their actions. We also studied the teachers’ attitudes towards this game and their understanding of game as conceptual model of parasitism through group discussions.

Our research questions are:

- How did the teachers succeed in playing a novel AR game and deducing the rules of the game?
- Was the game suitable to be used as a learning game?
- Could teachers perceive the game as a conceptual model of parasitism?

2 Theoretical framework

2.1 Learning and interest while gaming

It should be noted that “play” and “game” are two different concepts. While “free play”, often exhibited by children, has no agenda and goals are intrinsic and personal, games tend to have defined goals (Klopfer, Osterweil, Salen, Groff, & Roy, 2009). These goals can include win states and quantifiable points, and games have internal structures created by their rules. This does not mean that games are unduly constrained: the players seem to experiment very freely inside these constraints, with the understanding that they can fail (Squire & Steinkuehler, 2005). In fact, the potential to fail and learn from mistakes as a way to increase motivation is one of the hallmarks of gaming and it also makes gaming attractive from an educational point of view (Prensky, 2001). There are several other potential sources of greater engagement (Linnankylä, 2013): competitive settings, awards built in to gameplay, detachment from the real world, co-operation between students and feelings of adventure. Some games might rely more on real-time cooperation between players than other, more solitary ones. The idea is that there is a set of consistent rules which creates the sense that the game is fair.

The actual gaming experience has not been studied as much as the learning outcomes of gaming (Arnone et al., 2011). A study by Klisch et al. (2012) shows that players' perceived usability of the game and satisfaction with the game were the two best predictors for increase in content knowledge and attitudes toward science. Foster (2012) found two distinct strategies for playing: explorers who mainly explore the game world without set goals and goal seekers who strive intentionally for set goals. While both types learned during the gaming, only explorers valued the learning. In biology education, several games have been used successfully as teaching tools. The outcome has generally been increased interest (Cardona et al., 2007; Spiegel et al., 2008; Farley, 2013) and collaboration among students (Shaer et al., 2011). Computer games are also frequently played outside class time and are thus assumed to increase student learning (Farley, 2013). While there is less data on actual learning outcomes, large studies by Sadler et al. (2013; 2015) showed large effect sizes on increase in content knowledge. Rowe et al. (2010) found distinct game strategies for high and low-achieving students: while high achieving students had higher interest and concentrated on information gathering and processing, low-achieving students preferred novel gameplay elements and less intentional gaming.

Increased interest is one reason for educators to use games in general and digital games in particular. Interest is a multifaceted phenomenon: personal or individual interest means an intrinsic desire to understand phenomena which holds over time, whereas situational interest is ephemeral context-specific interest (Schraw & Lehman, 2001). It is difficult to control personal interest; thus most research has concentrated on situational interest. Digital games are expected to raise situational interest. Situational interest is traditionally excited in two phases: triggering of the interest and sustained interest (Hidi & Baird 1986). First it is necessary to capture the attention of the students and then provide the conditions for continuing attention. This has been refined to include personal interest in a four-phase model which includes triggered and maintained situational interest and leads to emerging and then well-developed personal interest (Hidi & Renninger, 2006).

2.2 Similarity between games and conceptual models

Breuer and Bente (2010) state that a game holds interest at several different levels: 1) the micro-level, where the reaction is born from simple inputs and outputs and these lead to simple mechanics of game play, which can be small rewards, advancements in the game or something as simple as moving the player's avatar in the game; 2) the narrative level, the storyline of the game which the player tries to uncover; and 3) the meta-level, understanding the rules of the game and manipulating the game's world, which roughly corresponds to metacognitive understanding of how the game works.

Successful gaming requires learning the mechanics of gameplay, not only at the micro-level but most of all at the meta-level. Games are a model of a specific situation and the meta-level is the structure of this model, whereas micro-level mechanics are only the consequences of implementing the model. Definite pedagogical benefits are that games traditionally have explicit rules that are easy to learn. This allows students to assess the conceptual models they have learnt and even think of ways to make the models more realistic (Jenkins, Purushotma, Weigel, Clinton, & Robinson, 2009). This can also potentially be linked to learning games, where the actual conceptual model behind the computer games matches to the conceptual model that students are expected to learn.

2.3 Augmented reality location-based gaming in education

Following the definition from Milgram & Kishino (1994) augmented reality is the supplementation of real-world environment by any computer-generated output, and it ranges from purely real environments to purely virtual environments. The hypothesized benefit of augmented realities is enhanced immersion in the game world, which could benefit learning (Dede, 2009). There are two distinct AR forms: location-aware and vision-based (Dunleavy & Dede, 2014). In location-aware AR, the players move in an area with the use of GPS tracking. Vision-based AR relies on the players pointing the digital device at an object (e.g., QR code). Both of these forms allow players to locate in the game and navigate in the game world.

Augmented reality can be used in both formal and informal learning. Location-based games are especially useful for informal education institutes such as zoos or museums, where additional information and even games can be created (Martin, Dikkers, Squire, & Gagnon, 2014;). In formal education, the most obvious targets have been in subject teaching for example of environmental sciences and history (Herbst, Braun, McCall, & Broll, 2008; Squire et al., 2006). In biology, such games have been developed mostly for outdoor education (e.g., Barab et al., 2009; Rogers et al., 2011; Eliasson et al., 2013) but they can also be used also for learning biomolecular structure or anatomy (Sankaranarayanan et al., 2003; Chien, Chen & Jeng, 2010). One of the strong points of location-based games is that the situation becomes concrete and conceptual knowledge can be correlated to actual location (Brown, Collins, & Duguid, 1989). It also provides an experience that students appreciate as authentic

(Rosenbaum, Klopfer, & Perry, 2006). There seems to be some evidence of added reflection (Squire & Jan, 2007), discussion between students (Rogers, et al., 2011) and physical activity (Magielse & Markopoulos, 2009), but also difficulties in implementing the AR teaching (Dunleavy, Dede, & Mitchell, 2008).

3 Creating the game: Parasite Race

We decided to build a game using parasite life cycles as the subject because the content belongs to biology education concerning the interactions of species' populations, one of the unifying principles of biology used in school curriculum (National Research Council, 2012; see also The Finnish National Board of Education, 2003; Uitto, 2012). As the backstory of the game, the parasite life cycle supplied a clear main objective, i.e., reaching the main host, and several subsidiary objectives along the life cycle, i.e., the intermediary hosts. Furthermore, it made it easy to build a gameplay experience with optional sequences for different actions. Assigning rules for achieving or losing points for each action led to constantly updating scores for players, which they could access at any time.

In the game, the players move freely in the authentic game area, which is shown also in the game map, based on Google map view, in tablet. They can see their own position on the map and also the locations of the hosts and actions. Players orient themselves with a map as they move in an authentic environment. The different actions and hosts are situated on the game map and the players need to move to responding sites in the authentic area to reach them. When player reaches right spot in authentic world the corresponding host or action pops up in the game.

In the beginning, each player has choice of three different parasites: sheep liver fluke, *Echinococcus sp*. and tape worm. The species have, species-specific hosts which that they have to reach. At the same time, the players also have to choose their strategy, which could emphasize on reproduction or growth. Neither, species nor strategy can be changed during game play. The setting of the game is that players start out in their main host and have to go through a complete lifecycle and end up back in the main host (Figure 1).

After the initial selections, the players are ready to start the game. To be able to infect the next host, there are generally two prerequisites: first of all, the player needs to have a high enough probability to infect host and the player needs to encounter the suitable host. This probability can be increased by performing actions related to the life cycle: reproduction, forming cysts, laying eggs and competing with other parasites. For every action, there are two options a player can choose from and the change in the infection probability depends on this selection and on their strategy. For example, all the actions with reproduction give more points to players who have chosen faster reproduction as their strategy (Table 2). The points collected for any action are a random number within a certain range. The range depends on the option that the player chooses within the action and the scenario they are playing in. The non-beneficial options used for the analysis of the gameplay are marked with gray. In many instances the progress to the next host requires laying eggs. This reduces points in any case and is needed only once, so we have counted all egg layings after the first one as non-beneficial.

The players can freely move to any host or action they wish. The game provides a warning if the player is trying to reach an unsuitable host or if they do not have enough points to infect their next host. The players do not have direct access to the model but they can see their accumulated points in real time at any point of the game. Thus they are able to deduce the effect of any actions by comparing the points before and after the action. We expected players who could apply their knowledge of evolution to select fewer non-beneficial options. As the scenario stays constant during the game play we also expected the players learn quickly what the mechanistically beneficial options are.

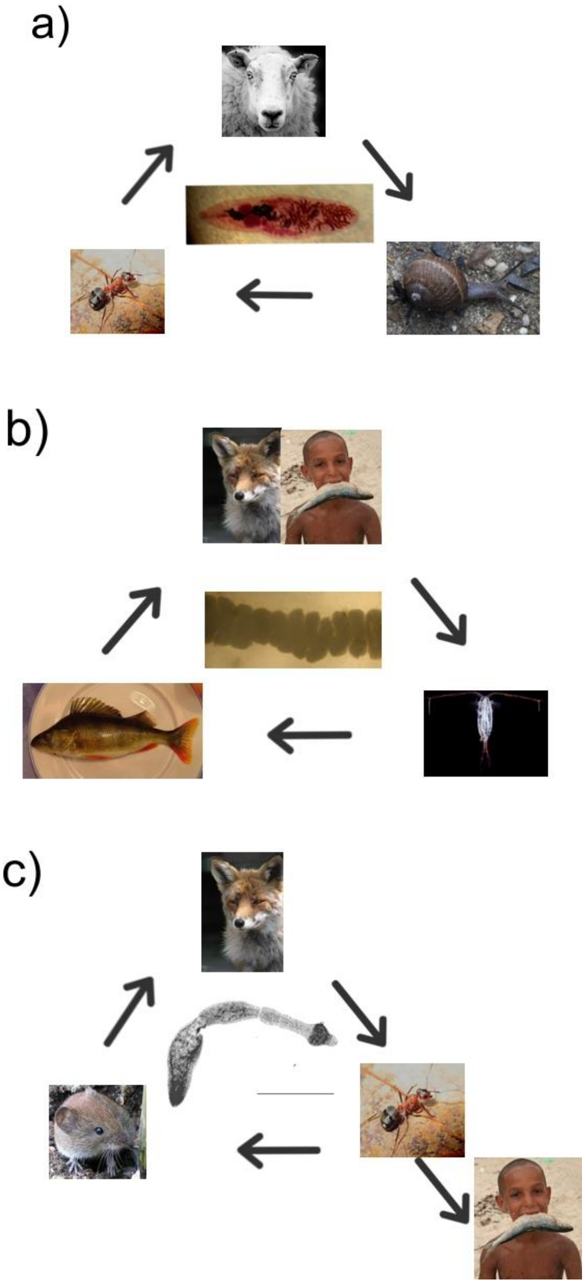

Figure 1. Different parasites the players can choose and their lifecycles. The parasite itself is depicted in the middle of the figures and the starting host is on top: a) sheep liver fluke's life cycle starts at the sheep and continues via snail and ant back to the sheep, b) tapeworm's life cycle starts at the human or fox and goes via copepods and perch and c) *Echinococcus* goes from main host fox in the feet of the ants to voles and then back to fox, though it can also accidentally infect humans.

In some cases there are other prerequisites: the parasite has to perform an action needed for the infection, depending on the real life cycle. This might be forming cysts in the muscles of the intermediate host or just laying eggs. For example, the sheep liver fluke needs to migrate to an ant's central nervous system before it is able to infect sheep.

Feedback is a crucial part of the gaming experience. Validation feedback shows the students' actions in the relation to the learning aims (Mory, 2004). It highlights mistakes and shows how to avoid these errors in the future. Examples of validation feedback in our game are directing the player to the right host and signaling when they are trying to infect the wrong host or lack prerequisites for infection. Motivational feedback supports students in their learning process and it depends strongly on their personal contexts (Mory, 2004). Thus, in our game, the students are motivated by advancing in the game through collecting more points. The students can also evaluate different strategies by comparing the points accumulated by different actions.

Table 2. The results of different actions within the game. The non-beneficial choices are marked in gray.

Action	Option	Emphasis on parasite's body growth speed	Emphasis on reproduction
Laying eggs	Inside	50% point increase	100% percent point increase
	Outside	Decrease 10 points	Decrease 5 points
Reproduction	Asexual	Random change between -10 and +20	Random increase between 0 and40 points
	Sexual	Random increase between 10 and16 points	Random increase between 16 and 20 points
Forming cysts	In the muscle tissue	Increase 20 points	Increase 20 points
	In other parts of the body	50% point increase	100% point increase
Competition	With growth	Random increase between 10 and 30 points	Random change between -5 and + 5 points
	With secretion	Random increase between 0 and 20 points	Random increase between 0 and 20 points

We used TaleBlazer (Scheller Teacher Education Program in Massachusetts Institute of Technology, see taleblazer.org) as the game maker. The main reason for choosing this game maker was that it is free to use and works on Android, which Samsung minitablets use. We did the programming by writing a simple script for the whole game with flowcharts (Figure 1). The graphical user interface of the TaleBlazer game maker is easy to use (Figure 2), and is similar to Scratch (Lifelong Kindergarten Group at the MIT Media Lab, see http://scratch.mit.edu/), which is frequently used in programming teaching. As TaleBlazer looks clear and simple and is a self-explanatory platform, this game should be easily playable.

The game maker divides the main constituents of the game into “agents” and “players”. In this game, the different parasite species are players and the agents are the hosts and actions needed to increase infection probability. The agents are located at fixed positions on the map and their scripts run when players come close to them. The programming of the game took substantial time: approximately 16 hours for a person with no previous experience with programming games or the graphic user interface programming tools. The most time-consuming part was the testing of the game.

The game itself is played on an application that works on iOS and Android operating systems (Figure 3). The game consists of a map tab in which the player can see their position, a player tab where the players can see their infection probability and a log tab where the players can review their game history.

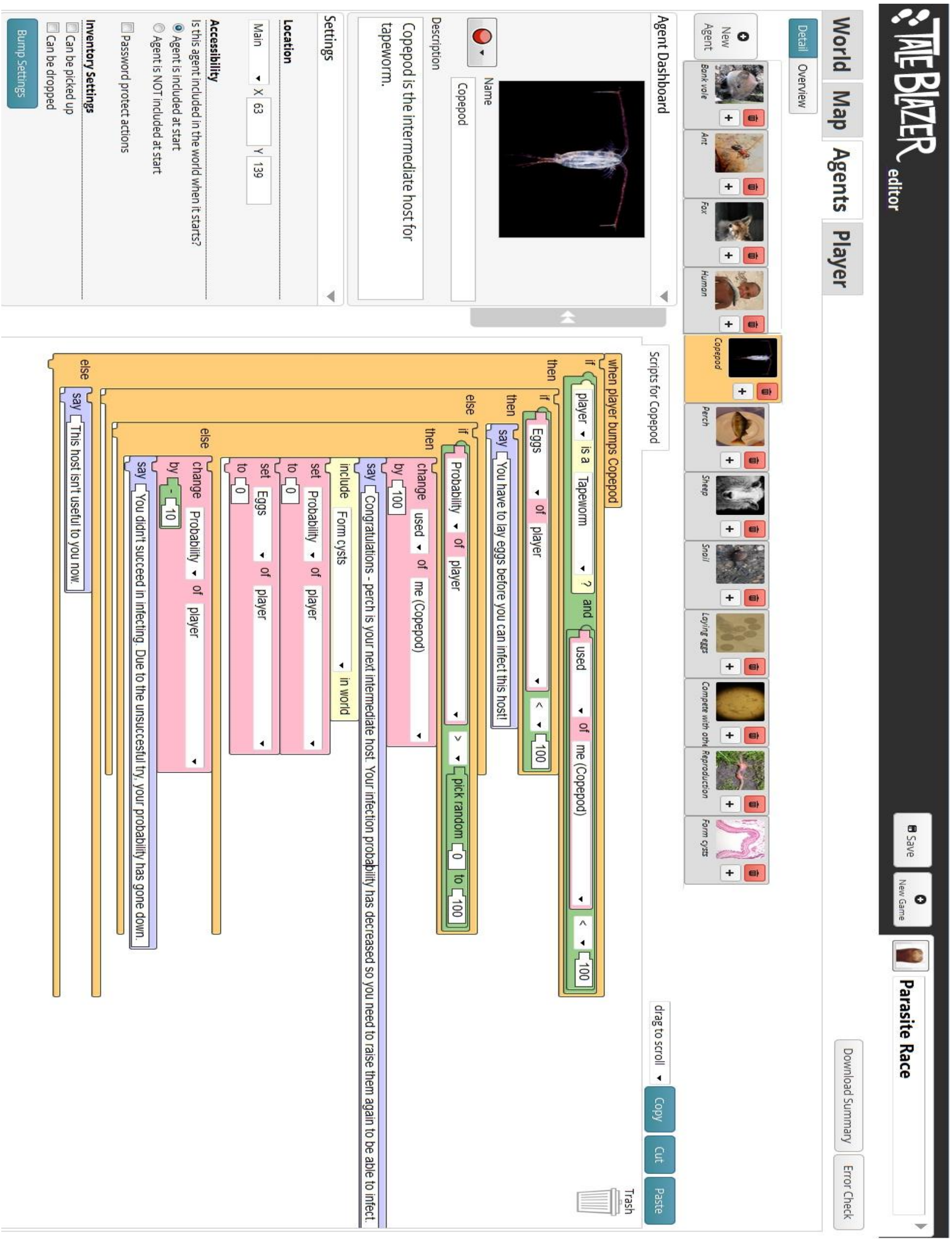

Figure 2. The graphical interface of TaleBlazer divides the main constituents of the game into "agents" and "players". In this game, the different parasites were players and agents corresponded to hosts and the actions needed to increase infection probability. The agents were located on fixed positions in the map and their scripts ran when players came close to the agents.

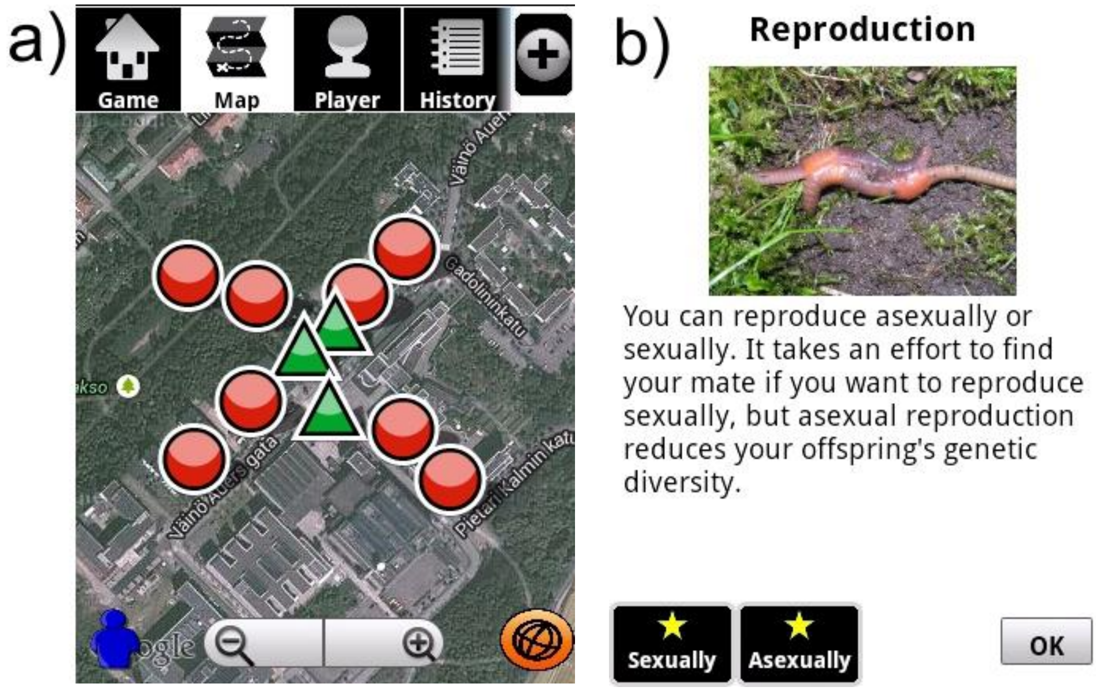

Figure 3. The user view of the final game in TaleBlazer app, including a) the Map tab and b) choice of the action. In the Map tab, the actions are marked with green triangles and different hosts with red circles. The points collected can be always seen in the Player tab.

The game is freely available for adaptation and modification (or remixing as TaleBlazer calls it) at http://taleblazer.org/gamePage/962 (in English) or http://taleblazer.org/gamePage/826 (in Finnish). Using the TaleBlazer app available free attaleblazer.org, the ready-made games can be loaded with game codes geiqnsj and gfjlcbv, respectively.

4 Materials and methods

4.1 Study context

We ran the game with a group of primary and secondary school teachers as part of their in-service training on mobile gaming, organized by the LUMA center at the University of Helsinki (an umbrella organization for promoting lifelong learning in STEM subjects: http://www.helsinki.fi/luma/english/). The training consisted of workshops and they could freely pick from the three workshops available. The one used for this study was called "Mobile gaming in evolutionary biology". The workshop was run three times, with the number of participants being from three to seven teachers per workshop. In every part of the study, the teachers could choose whether they wanted to participate in the study and two of the teachers opted out. All of the data was handled so that it could not be connected to the individual players.

4.2 The participants

We delivered prior to the workshop an online questionnaire to gauge the background information and interest of the teachers in mobile gaming. A total of fourteen teachers participated in the game play and group interviews, but one of the participants did not answer the pre-test questionnaire.

Of the participants 23 % were primary school teachers and 77% from secondary schools. All were biology teachers and the most common other subjects they taught were geography (77% of the respondents) and health education (54%). Most of the teachers were female; only two were male. The participants were mostly young, only one was over 50-years-old. Seven had been teachers for over 10 years. All the teachers, but one, were willing to increase the use of gaming in their teaching. Only two had previously been trained in mobile gaming, though another two mentioned that they had been self-studying the subject. None of the teachers were strangers to different kinds of games but computer games were rarely used and programming or virtual reality never. On why they would want to use more games, three different reasons were named more than once (in order of number of mentions): motivating the students (e.g., “the learning does not feel like learning in a relaxed atmosphere”), individualizing the teaching (“games give something to every kind of learner”) and variation in teaching methods (“they are motivating and bring variation to teaching methods”). Also mentioned were group working skills and making difficult concepts concrete. Our participants had similar attitudes as previous large surveys in Finland found in teachers (Kankaanranta & Puhakka, 2008; Mustikkamäki, 2012; Nousiainen, 2013b).

4.3 Data collection

We started the game with minimal guidance, so that we talked through how the game play worked, what the objectives were for the players and how to use the tablet. We did not explain anything about parasites or evolutionary theory but mentioned that the game simulates how parasites work and that the scenario they chose would have an effect on how points were accumulated. 15 minutes were used for the introduction, 45 minutes for the game and 30 minutes for the discussion afterwards. The game was set in the Kumpula campus of University of Helsinki, Finland. We collected observational data during the game play about the teachers’ progress. We noted if any of the teachers needed additional help or clarification, how long it took to finish the game and possible reasons to give up playing. The game itself recorded each action the players took, so we could have an outline of each player’s game.

After playing the game, the teachers were asked to join the reflective group interview to find out how well the game had worked. The teachers were seated in a classroom and one of the authors was present to lead the interview in a semi-structured way and to take notes. We asked an open-ended warm-up question: “What did you think of the game?” We wrote down the replies and also noted whether other teachers agreed with the statements or if they had opposing ideas. We then asked which properties of the game they liked and which they did not like. We wrote down the properties mentioned and also noted if these were general or individual opinions in the group.

To assess how well the teachers understood the game as a model of parasite life cycle, we asked how they would have changed the game mechanics to make it more realistic. We also asked how useful the game was and whether they felt they could use something similar in their classroom practice. If the topic of programming games did not otherwise come up, we finished interview with questions on whether the teachers could program these games themselves and whether their students would be able to program games.

4.4 Analyses

The game log did not record the points scored by each of the participants but we could deduce when the players progressed to the next level and if they successfully completed the game. We measured how often the players made non-beneficial choices: these were either the worse of two choices in an action or simply actions that were not beneficial as a whole (Table 2, 3). As some of the choices were sometimes necessary, but did not accumulate points (like laying eggs), we considered any actions more than necessary to be non-beneficial. For example in the case of player depicted in Table 3, the player had chosen strategy of growth and thus reproduction was non-beneficial for the player. We compared the amount of beneficial versus non-beneficial choices in participants with Mann-Whitney U test.

Table 3. An example of one player's actions. In the first host, the player chose 4 non-beneficial choices, whereas in the second host there were none. The non-beneficial choices are marked in grey.

Sequence	First host	Second host
1	Asexual reproduction	Competition by growth
2	Sexual production	Competition by growth
3	Competition by growth	Laying eggs
4	Sexual production	Cysts in other places
5	Competition by poison	
6	Laying eggs	
7	Sexual production	
8	Competition by growth	
9	Competition by growth	

We used thematic analysis to examine the group interviews. We classified the teachers' ideas to closely defined categories based on our research questions. We concurrently used categories to create the themes and sub-themes. The group interviews were not directly comparable, as different groups had very different compositions and they had different general moods after playing the game. Thus, the context needed to be taken into account.

5 Results

5.1 Teachers' success in gaming

The game itself drew diverse reactions from the teachers participating in the game. Two of the teachers got frustrated after ten minutes of playing without progress. Those participants suggested that their students would also have lost their patience playing the game. Five of the teachers succeeded in completing the life cycle in 45 minutes (Figure 4), the fastest being 17 minutes. Some of those who had been able to complete the life cycle explicitly mentioned in the group interview that during the game they performed the actions and then looked at how their infection probability changed, whereas the unsuccessful players just wandered around in the game area without a clear idea of what to do.

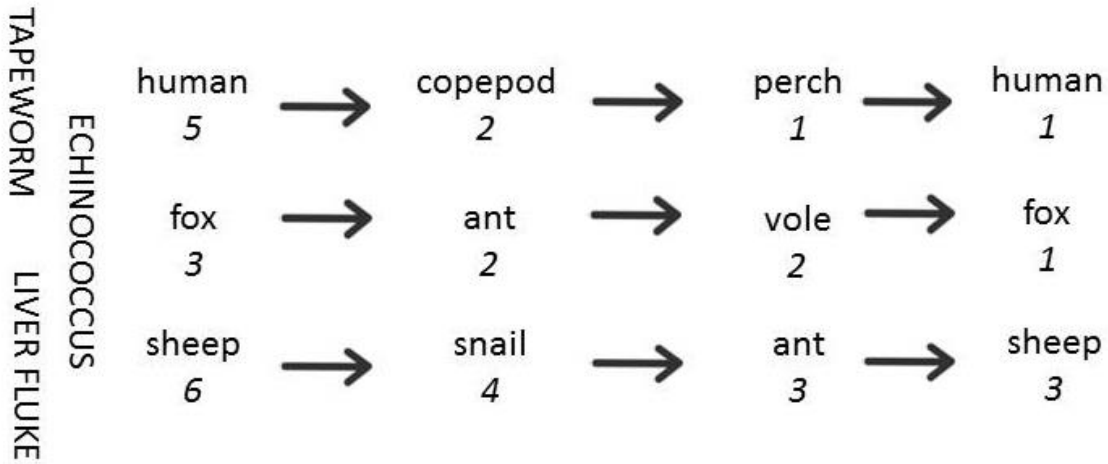

Figure 4. The different parasites played by the participants and how far the participants progressed in the game. The number below the host means how many players reached that intermediate or definitive host. The first number in each life cycle corresponds to the total number of players choosing that parasite and the last number to how many players completed the life cycle.

In their first host, the players chose the non-beneficial options 31% of the time. There was then a clear decrease in "wrong" choices: in subsequent hosts, the proportions were 10% and 0%. There was no significant difference in the number of non-beneficial choices between those who succeeded in getting to the second host and those who did: in their first host the unsuccessful players had 33% of the choices wrong, whereas in successful players the proportion was 28% (Mann-Whitney U-test: $W_{13} = 23$, $p = 0.943$). There was however a significant difference as the successful players performed more total actions compared to unsuccessful players (Mann-Whitney U-test: $M_{successful} = 7.25$, $SD_{successful} = 2.33$, $M_{unsuccessful} = 4.2$, $SD_{unsuccessful} = 1.21$, $W_{13} = 7$, $p = 0.030$).

5.2 Teachers' ideas on using games for teaching conceptual models

Three general themes emerged from the group discussion: personal experiences on playing the game, developing more complete conceptual model of parasitism and usability of the game (Table 4). Usually after one teacher had expressed his or her opinion, the others showed their agreement or disagreement clearly. Thus each group is rated along the opinions teachers expressed as the opinion only being representative of one teacher's opinion, opinion having some support or all teachers agreeing with the opinion.

Table 4. The emerging themes from group interviews. A = supported by all participants, B = supported by some participants (2-4), C = supported by one participant

Theme	Sub-themes	Group 1 *n = 4*	Group 2 *n = 7*	Group 3 *n =3*
Personal experiences	Outdoor game as a positive experience	B	A	A
	Too many technical issues	A	B	
	Interesting to play	C	B	B
	Contents suitable for school teaching	B	B	A
	Better guidelines needed	B	C	
	Interface underdeveloped	B	C	C
	Gameplay not intuitive	C	B	
Developing more complete model	Hosts should be moving targets	C	B	A
	Hosts should not always be available		B	B
	Interaction between players needed	C	A	A
	Reproduction linked more clearly to finding a mate		C	
	Uncoupling of hosts and actions			B
	Reducing the effect of choice	C		
	More foraging options		C	
	Reproduction and finding mate more closely linked			C
Usability	No use in school	B		
	Could be used as it is		B	C
	Could be used if easier	C		
	Could be used with extended introduction	B	C	B
	Programming too difficult for me	B	B	B
	Programming suitable for some students	C	B	A

5.2.1 Teachers showed positive attitude towards the game

In all groups, the first teachers to answer the questions spoke about their personal experience and how well they fared in the game. In all groups the teachers expressed, in general, positive attitude towards the game being set outdoors:

> "Outdoor education is a refreshing alternative to the classroom." *Teacher in Group 1*
> "Students generally prefer outdoor classes." *Teacher in Group 3*
> "Students remember better what they have done outdoors." *Teacher in Group 2*

Teachers also liked the contents of the game. While parasites are not explicitly mentioned in the national curriculum, teachers felt that the contents were a good fit for biology teaching and they thought the contents were interesting.

> "I actually learned new things about parasite biology." *Teacher in Group 3*

Teachers expressed dislike towards technical problems and they also wanted better guidance on how to play the game. In all groups, teachers found the game-playing interface too underdeveloped, with too many unintuitive or unclear functions, although they did not think it was a crucial problem. Some of them deemed the game too difficult for their students. These were also the teachers who gave up playing themselves.

> "During the first five minutes I really did not know what to do. With better guidance, the students would be able to figure out right away what to do and have less chances of getting frustrated." *Teacher in Group 2*.
> "Our students would give up playing this game in five minutes." *Teacher in Group 1*

5.2.2 Models are limited by complexity

When asked in group interview how the game could be made more realistic, the most often-mentioned enhancement was to make the hosts moving targets or that the hosts not be made available all the time. The actions were given as static targets in the map and there were several suggestions on how this could be made more realistic: reproduction and competition could be related more strongly to finding a mate or competing individuals. This could also be used to broaden the game to multiplayer approach.

> "In real life, the parasites do not really move, or they do only at the larval stage, whereas in this game they moved and the hosts stayed still. "*Teacher in Group 2*

Also, there could be more explicit foraging actions like choosing a site to feed. Some of the players were also thinking about how realistic a picture of parasite evolution the game gives: it now implies that the parasite could intentionally decide how to behave.

> "The parasites cannot really decide what to do; they do not have the option to choose. Could it be better that the players do not have choices after their initial choice of character?" *Teacher in Group 1*

In the two last groups, teachers mentioned that making a more complex model would make it much more difficult to learn gameplay. In last group, teacher expressed understanding that this is similar to teaching basic biology concepts.

> "This is a bit similar to teaching: we need to keep concepts simple enough so students can easily learn them." *Teacher in Group 3.*

5.2.3 Programming could be used as teaching method

The teachers expressed their concern that the game is too difficult for lower secondary school students or at least that it would need an extensive introduction parasite life cycles. Two of the teachers who gave up playing after an unsuccessful start were still irate and expressed their reservations on the usefulness of the game very clearly. The other teachers held a wide range of opinions on how useful the game could be, with the ones who finished the game successfully having the most positive opinions. Teachers were skeptical about their ability to program the games although many of the teachers suggested that this kind of programming task could suit the students well.

> "I have two students who would be enthusiastic about the possibility to do actual game." *Teacher in Group 3*
> "I would not be able to program this kind of game, but my students could. Many of them are more fluent with computers than teachers." *Teacher in Group 1*

6 Discussion

6.1 Sustained interest correlates with success

Our preliminary questionnaire revealed a quite uniform group of teachers who were in principle enthusiastic about games and willing to use more games. Nevertheless, their actual game playing data and group discussion revealed that they held a wide variety of different approaches to the use of the games.

There was clear differential success with participants as only 5 out of 13 participants finished the game. The main component of success was the willingness to try and even fail**:** there was no difference in how often the successful players made wrong choices in the beginning, but there was a clear difference in the number of the actions they performed (Figure 4). This begs the question, of whether the most successful players were the most motivated. In our game, it is impossible to tease apart motivation and the skills to analytically approach the game. Even though the questionnaire did not show any differences in attitude to gaming, the players demonstrated markedly different playing strategies: some tried again if they made a wrong decision while others were quick to give up. This could indicate a difference in interest, where the game failed in capturing the situational interest of those teachers who were not personally interested in the game (Schraw & Lehman, 2001). It needs to be emphasized that it is necessary for a game to stimulate student persistence in order to produce learning outcomes (Ainley, Hidi, & Berndorff, 2002). The motivation to try and fail could also be related to mastery experiences (Bandura, 1977) in gaming: the players with sufficient success experiences are motivated to try hardest, which generates a virtuous circle of motivation and success thus strengthening self-efficacy (Bandura, 1977; Klimmt & Hartmann, 2006) in gaming. Mastery experiences may also have boosted the motivation to try and fail of those teachers, who had already been successful in some game before (c.f. Bandura, 1977). Teachers that could apply their gaming skills, could also be more successful to perform the gaming tasks in time.

6.2 Understanding computer game as simulation of conceptual model

The group interview revealed that playing the game outside of the context of teaching about parasites and evolutionary strategies was difficult. Though most of the teachers were competent biology teachers they had problems adapting to the decisions they needed to make in the game. In a classroom context, with more time available to discuss evolution and parasites, this might have not been such a big problem, but the guidance should have stressed the context more. The teachers may not have been able to apply their competences as biology teachers when using the new learning environment, the game.

The players also seemed to understand the game as something they just needed to go and do – rather than think analytically about. This might be due to the expectations that the players had towards “a game”, the introduction they were given or the interpretation they generated after starting to play the game and seeing how it looked. **Thus, emphasizing the point of the scientific models before gaming might lead players in a more fruitful direction.**

For those participants, who persisted and succeeded in getting to second host, the decrease in errors (e.g., Table 3) suggests a correlation with how well players understood the game mechanics and how far they progressed. There was clear metacognitive reasoning happening: the successful players were able to relate their actions to the changes in their score and then choose the most effective actions. Based on the gameplay data and group interview, it seems that most of the teachers (8 out of 14) did not seem to understand the game-as-model idea before they started to reflect actively on how they would have made the game better. They could answer simple questions on which actions gave them points and which cost them points; with more time and another round of gaming, they might have been able to figure out how the model works with directed questions and discussions. In the group interview, participants from two of the groups understood the link between the usefulness of the model and its simplicity.

We built our game as a simulation of authentic life cycle theories of parasites. This had an explicit objective of making scientific models more tangible and concrete. School textbooks do not do a good job of presenting the scientific models (Aivelo & Uitto, 2014; Aivelo & Uitto, 2015; Gericke & Hagberg, 2010) of biological concepts and processes, and students tend to have naïve ideas of the scientific models (Grosslight, Unger, Jay, & Smith, 1991) which simulation games could make more explicit. Thus games could be a vehicle for making scientific models visible, especially if the students are making the games themselves. There is however a debate on how well the games teach the properties of complex models and how much they teach only simple heuristics or the hidden curriculum where the underlying model is left out (Squire, 2006). In this study, those players who did not understand the game mechanics belonged to this group. Hargreaves (2005) has endorsed strongly integrating self-reflection in classroom practice. This reflection is thought to also promote metacognitive development and motivation to learn. When students are expected to build their own models, and it enhances both content knowledge and understanding of scientific processes (Gobert & Pallant, 2004). **This study highlights that reflection is needed not only during the game, but also before and afterwards.**

6.3 Adoption of gaming and programming

There was a clear benefit in having an augmented reality game: ***the teachers seemed to perceive the game as something more substantial ("actually doing things") when they had to leave the classroom (Table 4).*** This is also one of the reasons AR games could make an important contribution in formal education. We did not explicitly test for increased content knowledge, but some teachers explicitly mentioned during group interviews that they had learned new things. One of the downsides in our case was that the game was not strongly connected to a real-life spatial context: there was also no evidence that setting the game in spatial context made the learning any more tangible for the players. This could have changed if there were a connection between the actual environment and the game.

With the exception of some of the teachers in the first group, the teachers had generally positive attitude towards the game, and they could see it being used in teaching. Nevertheless, the teachers did not feel competent to design games themselves. In contrast, the teachers were more positive toward the students programming their own games. Actual programming has been assumed to be a more effective method of learning than playing games (George, Lavoué, & Monterrat, 2012; Kafai, 2006). The experience of programming is very different from normal school tasks and it can thus improve learning (Nousiainen, 2008). George et al. (2012) compare the student programming a game to the teacher's position: to be able to create a game, students need to understand the separate phenomena and then put them in a sensible context. While there have been early calls for programming in biology education (Ploger & Carlock, 1991), programming has very rarely been used in non-tertiary biology education and even more rarely studied. Nevertheless, programming seems to enhance learning by facilitating student representations of crucial conceptual models (Ploger, 1991).

6.4 Limitations of the study and future research

Our study is limited by the sample size and the amount of the data. We had no opportunity to interview participants more thoroughly on how they see conceptual models of central biological concepts. We should be also careful in deducing from the behavior of students how students would behave. There several crucial differences between teachers and students: teachers are more educated, they should be more reflective during the game on how well it suits as teaching material and it is expected they are less accustomed to computer games. Nevertheless, the behavioral data from mobile games gives us very detailed data and allows us to draw at least preliminary suggestions. We are planning to perform a more thorough study of the usability of programming AR games with upper secondary school students to increase understanding of conceptual models.

More research on gaming is an imperative as the teaching and curriculum development should be evidence-based, especially research on the efficacy of how well programming the games could be used in improving the understanding of scientific models in biology. There are evident barriers to the development and innovation of educational games. One of the problems is small, fragmented and unambitious development projects (Klopfer et al., 2009). The products, whether they are teaching methods games or programming platforms, should be scalable to achieve a high impact. Common problems also include limited investment in learning technology: even though there would be effective learning games, teacher competence and availability of suitable equipment could limit use of computer games in schools.

7 Conclusions

In our perspective, the main reason for using digital games is that they can fill a plethora of different functions. Anyone advocating the increased use of games should bear in mind Eck's (2006) message: ”Of the several technology ‘learning revolutions’ during the last quarter-century, most have failed to achieve even half of their promise. Although there are many reasons for this, the primary fault lies with our inability (or unwillingness) to distinguish between the medium and the message.” We suggest that digital games truly enable more diverse teaching strategies, but the gaming needs to be engaged with a clear idea of which strategies are to be used. The teachers also saw this possibility while reflecting on how some of their students might be very motivated to try programming biology games. As a general rule, teachers who were not competent in gaming also did not want to use games in their teaching. It is probable that this also holds the other way round: more competent gamers feel that games have more to give in teaching.

This study shows that programming and playing an AR location-based mobile game could be used to enhance students' understanding of scientific models and it also showcases many of the problems faced by this approach. The game revealed remarkable differences in game-playing success between the participants. The game playing data further showed that success in the game did not correlate with how well the teachers did at the beginning of the game but rather how persistent they were. Thus, we can expect that situational interest holds a key to the success of the AR game. It should be borne in mind that the game was tested with primary and secondary school biology teachers and thus also needs more testing on the students.

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