Using Serious Games in Computer Science Education

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ABSTRACT

Games are generally considered to be motivating and engaging and people spend a lot of time playing recreational games. Serious games can be used in Computer Science (CS) education to offer a different type of method to learn and discuss relevant topics.

This paper presents a pilot study of using serious games at a Data Structures and Algorithms course. The games that were used were either card games or they were played on a blackboard. The results of the pilot study seem promising and we will use the games also in next year's course. In addition, this paper raises discussion about using serious games in CS education. The main points of discussion are, how serious games can be used efficiently and how to evaluate the effects of using games?

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education—*Computer science education*

General Terms

Algorithms, Experimentation, Human Factors

Keywords

serious games, game based learning, computer science education, data structures and algorithms, card games

1. INTRODUCTION

Games are used in many different ways in computer science education. Games are also often a big part of students' recreational hobbies. Serious games are games that have other objectives than pure entertainment and they include all aspects of education: teaching, training, and informing [8].

Serious games can be a motivating way to teach computer science topics. A key element in games in general, is a high level of interaction among the players. A player must be actively involved in the game in order to succeed in it. Shabanah et al. [11] propose playing computer games as a new form of active engagement that combines all five active forms of *Active Engagement Taxonomy* presented by Naps et al. [9].

There are some elements in games that can be beneficial in education. For example, a well designed game can increase students' motivation level to learn the topic of the game. In group games, players can learn collaboratively with other students. Some students can also be motivated by the competitive nature of games.

Serious games are often associated with computer games. However, computer games are not the only way to use games in education. In this paper, we describe a case study where a set of games was used in a Data Structures and Algorithms course. The games were either card games or they were played on a blackboard.

We give an overview of using games in education and present some different approaches used in game based learning in Section 2. In Section 3, a case study of using card games in CS education is presented. Analysis and experiences of the case study are reported in Section 4. Finally, discussion of using serious games in CS education is presented in Section 5.

2. RELATED WORK

The use of recreational computer games has increased over the past years. People spend voluntarily a lot of time playing games, indicating that, in general, games are experienced as motivating and engaging. However, we can not assume that representing something in a form of a game makes it motivating. Also, we can not assume that all people are motivated by games.

Whitton [13] conducted a study to examine the motivational potential of using computer games in higher education. The results indicated that some of the students did find games motivating and some of the students did not. However, even those who were not intrinsically motivated by games, thought positively about using games if it was to most effective way to learn something.

Kirriemuir and McFarlane [7] state two key themes that are common to the development of games for education:

- The desire to harness the motivational power of games in order to making learning fun.
- A belief that learning through doing in games such as simulations offers a powerful learning tool.

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They also state that "making learning fun" often implicitly assumes that students do not enjoy learning. This assumption might be the reason why in some educational games, the learning is concealed within the game. This attempt might in fact lower the level of motivation towards the game.

Connolly et al. [2] performed a literature search on game based learning and concluded that even though games are increasingly used in computing education, there are still only few empirical studies conducted about the effects of the games. Clearly there is a need for future research on evaluating the learning effects of the used games.

Some wariness should be taken when applying results of using serious games to a different group of students or to another context. Hays [5] brings out some issues about generalization of the game based learning results: although there are effective learning results for several different topics, this does not indicate whether some other learning objective would benefit from game based learning. Also, results for one group of learners should not be generalized to all learners.

Typically, the social interaction among players of a game is essential. Also, many recreational games rely heavily on the fact that players communicate during the game. Ines and Abdelkader [6] propose a framework for analyzing the social aspects of serious games. They say that social learning and social presence are essential for learning in serious games and therefore the social presence "potential" should be analyzed. They focus on serious games that are played in virtual worlds.

2.1 Serious Games in Computer Science Education

Games can be applied in CS education in many different ways. Programming courses offer a natural environment for games related programming tasks. However, programming tasks do not have to be the only way games are utilized. Wallace et al. [12] describe four different approaches to use games in education:

- Students learn by implementing games.
- Students learn by writing programs that implement a critical aspect of the game.
- Students learn by writing programs that act as a player in an existing game.
- Students learn by playing educational games.

According to Wallace et al., the last approach is not as common in CS education than the others. That is not a surprise, since programming skills are an essential part of computer science education. However, there are examples where the last approach is used in CS education.

Hainey et al. [3] describe the use and evaluation of game based learning application to teach requirements collection and analysis. The students played a game where they had to manage and deliver a number of software development projects. Hainey et al. used a pre-test/post-test and a control goup/experimental group to evaluate the effect of game based learning compared to the traditional methods. They found out that game based learning can be a suitable approach in teaching requirements collection and analysis. They had students from two education levels and they concluded that initial knowledge should be taken into account when applying game based methods in teaching. In their experiment, the students with better prior knowledge benefited more from the games.

Shabanah et al. [11] describe the use of computer games in teaching algorithms. They present a game development tool *Algorithm Game Designer* and a game engine *SAVGEngine* that can be used to create new algorithm games. They propose prototypes of games that are intended to increase the engagement of the players and therefore improve the motivation and learning outcomes.

2.1.1 Non-computer games

Serious games and game based learning are often associated with computer games. High engagement and motivating learning methods can also be achieved with games and puzzles that do not use a computer. For example, Parhami [10] shows how puzzles can be used to motivate students and to introduce important computer engineering concepts.

Hamey [4] has used a game called *The Security Protocol Game* when teaching secure communication protocols. The game is played in small groups using physical elements, such as colored envelopes, papers and key tokens. The game allows players to simulate the use of data communication protocols and explore different attacks against them. They state that the game reveals the issues of confidentiality, integrity, authentication and non-repudiation in secure communication protocols.

Bell et al. [1] describe a teaching method called *Computer Science Unplugged* that uses games and other activities to introduce computer science concepts. The activities are designed to teach students about various computer science concepts and they are suitable to students as young as five to twelve years old.

2.2 Summary

Games have been utilized in several different ways in computing education. Many experiments of using games have been made, but there is a lack of empirical studies about the effects of the games. It is also difficult to apply results from evaluation studies to another context or target group. Therefore, game based learning is clearly a field that needs further research.

3. CASE STUDY AT DATA STRUCTURES AND ALGORITHMS COURSE

The use of serious games was piloted at the Data Structures and Algorithms course in Aalto University during spring semester 2011. The games were specially designed for the course and consisted of three card games and one game that was played on a blackboard. Students were informed that the games are prototypes and therefore, for example, the appearance of the cards was not groomed. In addition, students were free to suggest any improvements to the game rules.

Each student could participate in one game session that lasted for 1.5 hours. Participating was not compulsory, but students earned points if they participated in this special lab session. The course contained total of 10 lab sessions that resulted in 40% of the course grade.

The main purpose of the pilot was to find out whether this kind of teaching method would be suitable for the course in

future. We were also hoping to get same ideas of how to improve the games and how to integrate the games to the course.

3.1 Students

There were two groups of students who participated in the course. Majority of the students were CS major students who took part in the regular course. There were also students who participated in an advanced programming course, meaning that they voluntarily took part in teaching that was more in-depth than regular CS teaching. The students in the advanced programming group had a separate game session.

3.2 Games

There were four games that were played in the game sessions. The underlaying concept of the games was to raise questions that the students should find answers to. Students were able to use the course material while playing the games and also there were one or two staff members that they could ask for advise.

The games were: *SortingGame*, *SortingCasino*, *Secret rule* and *Draw and guess*. SortingGame and SortingCasino are card games about sorting algorithms and related concepts. The basic concept of both games is that the players have to match an algorithm and criteria that are valid for the algorithm. A criterion can be, for example, *stable*, which means that all the algorithms that are stable can be matched to that criterion.

Similar skills are needed in both games, but the game mechanisms are different. In SortingGame, players first place down some criteria and then they have to place down an algorithm that matches the criteria. The player who placed down an algorithm with the best time complexity, wins the round. SortingCasino resembles the card game "Casino". In SortingCasino, players collect cards from the table by matching corresponding algorithm with a valid criterion. Both games use the same decks of cards.

Secret rule covers all the topics of the course. The deck consist of cards that have all the data structures and algorithms taught in the course. The main idea is that the dealer makes up a secret rule that the other players try to figure out. A secret rule can be for example: "A linear data structure". On each turn, a player puts one card on the table trying to match the secret rule, and the dealer acts as a judge. The advantage of this game is that the difficulty level is purely defined by the secret rule, which is made by the students.

In Draw and guess, students are divided into two groups. The deck of cards consist of course concepts. On each turn, a student has to draw the concept to the blackboard. If his or her own team guesses the correct concept, they receive a point. The opposite team can also guess the concept and steal the point.

3.3 Game Session

The games rely heavily on the fact that the players discuss the issues that arise during the game. The games do not provide much educational content that can be learned from the playing cards. Rather they raise questions and force players to make decisions about the course topics. It is up to the players to find out the right answers to the questions.

It is important that the communication between the players is made as easy as possible. That is one reason why we decided to use playing cards instead of implementing similar games in a virtual learning environment. A lot of the educational value of these particular games is lost if the players fail to communicate and discuss the questions risen from the game.

Having the players sit at a same table does not guarantee that they will be active in discussing the issues. It is essential that the atmosphere of the game session is such that students are not afraid to ask any kind of questions from each other or from the course staff. The students were free to form playing groups by themselves enabling them to play with people they knew beforehand. Course staff also joined the games with students and promoted discussion of the topics risen from the games.

A total of four game sessions were held and each session had 9-15 students. Each session lasted 1.5 hours so there was not much time per a game. Students formed game groups of 3-5 persons. First, all groups played SortingGame. Because of the limited time, groups could decide if they wanted to play SortingCasino or Secret rule next. At the end, Draw and guess was played together with all students.

Students were advised to discuss the aspects that rise from the game together and find solutions from the course material or asking from others. In addition, the game rules encourage players to justify their actions in case there is disagreement among the players.

4. ANALYSIS AND EXPERIENCES

Students' experiences of the use of serious games in the course were collected with a questionnaire that they filled out after the game session. In addition, participating in the games offered us an insight to some of the students' misconceptions that were revealed while playing the games.

4.1 Experiences

Creating an atmosphere where students freely ask questions about the content and the rules of the game is essential, because the games were designed to raise questions. We found out that a good way to enhance it, is to join the games with the students. It also provides good insight to the students' understanding of the topics. Here are some typical questions that rose during the game play:

- What is the definition of the term *in-place*?
- Is Quicksort a stable algorithm?
- What is the difference between $\theta(N^2)$ and $O(N^2)$?

One of the issues of the game session was the limited time. There was not enough time to go deeply into any of the games. Basically, students were able to try out the games, but not to spend too much time on one game. This is due to the fact that we wanted to try out all the games with the students for this pilot study. However, when it comes to learning from the games, it might have been more beneficial to concentrate on one or two games for the session.

4.2 Questionnaire

After the game session, students were asked to fill out a questionnaire. The questionnaire contained questions about the session and games, as well as possibility to give open ended feedback.

Table 1: Feedback on the usefulness of the game session in general. Students had to choose one claim that best suited their opinions.

	Regular course (N=36)	Advanced prog. (N=9)
Games do not seem to be a sensible teaching method even if they are developed further.	3%	0%
Games did not work well now, but in principle they seem like a sensible teaching method, if they are developed further in a right direction.	3%	33%
Games are a sensible teaching method in the course, but some of their features should be improved notably.	56%	33%
Games are a sensible teaching method in the course and they do not need any drastic changes, at most some small refinements.	35%	33%
Something else.	3%	0%

The first question of the questionnaire considered the usefulness of the game session in general. The results are shown in Table 1. The answers made by students in the regular course and the students in the advanced programming course are handled separately. It can be seen that the majority of students considered that games were a sensible teaching method. However, many of them thought that some features should be improved notably. When comparing the feedback from the two student groups, it can be seen that the advanced programming students did not find the games as beneficial as the students in the regular course.

Second question of the questionnaire considered students' motivation and learning during the games. Students where able to rate each statement with a number from 1 (fully disagree) to 4 (fully agree). The results are shown in Table 2. It can be seen that majority agreed that the games raised questions and that they learned new things while playing. Also, it was clearly seen beneficial that the games were played with other students. It is noteworthy that the advanced programming students gave less points on average and the biggest difference between the two groups is about the question whether playing raised questions about course topics.

4.2.1 Open ended feedback

Students were also able to provide open ended feedback about the games and the game session. There were positive and negative feedback about the game session and also some improvement suggestions for the games. Here are some examples:

- A good way to complete a lab session and recap course topics freely. Discussion confirmed my learning.
- Rules of the games are too open to interpretations.
- It was nice to try, but maybe I'm not the type of person who would like games to be more common teaching method.
- Nice alternative lab session, where the course topics were covered in a whole new way.

4.2.2 Mapping to exam results

The main purpose of the game session was to pilot the new teaching method and to test the game prototypes with the students. In addition, one goal was to teach the course topics. The number of students was fairly low, so we can not draw any definite conclusions by looking at their exam performance. However, we can search some interesting findings between the feedback and exam results that can be used as hypothesis for future research.

A total of 36 students participated in the regular course's game session and 33 of them completed the course exam. 21 students did not participate in the game session, but took the exam. Most of the games played in the course considered sorting algorithms. In the exam, there was one question about sorting algorithms. The maximum points for the question was 9. For that question, the average points for the students who participated in the game session was 5.8 and for the students who did not participate, it was 5.6. The students in the advanced programming course were excluded, because they did not take the same course exam.

Students' answers to motivation and learning during the game session were mapped to their results in the sorting algorithms question in the exam. The mean question points and the number of students who answered similarly to the feedback question, are reported in Table 3.

Even thought we did not examine the statistical differences, since the number of students was low, it can be seen that the biggest differences in question points were in feedback questions 3 and 4. The students who answered that they fully agree with the fact that playing raised questions about course topics (question 3), averaged 6.3 in the exam question. On the other hand, students who somewhat agreed, averaged only 5.5. Similarly, the students who fully agreed that playing is motivating way to discuss course topics (question 4), scored better points than the students who only somewhat agreed.

It seems that the students who considered playing more motivating and faced more questions while playing, succeeded better in the exam question about sorting algorithms. This raises questions whether the game benefited the students, or are the results just indicating that students who actively participate in class, score better in the exam? One hypothesis for future research could be that facing more questions during SortingGame and SortingCasino, results in better understanding of sorting algorithms.

The games are designed so that you have to actively search the answers to the questions risen in the game. It is important that the players are motivated to playing and finding the answers. This puts challenges for developing the games so that the players are encouraged to question other players' choices and to justify their own decisions in the game even more than now.

4.3 Lessons Learned and Future Ideas

This pilot provided us some valuable information on using

Table 2: Students' answers about motivation and learning during the game session (1 (fully disagree) - 4 (fully agree)). Number of responses and means for both student groups.

	Regular course					Advanced programming				
Feedback given	1	2	3	4	Mean	1	2	3	4	Mean
I learnt new things during the game session.	0	3	20	13	3.28	1	2	6	0	2.56
Playing confirmed things I knew beforehand.	0	4	20	12	3.22	1	0	6	2	3.00
Playing raised questions about course topics.	0	0	18	18	3.5	2	1	6	0	2.44
Playing is motivating way to discuss course topics.	0	5	15	16	3.31	0	2	7	0	2.78
It was beneficial to play with others and not e.g. against AI.	0	2	7	27	3,69	0	1	2	6	3.56
I am interested in playing more these kind of games.	1	6	22	7	2.97	0	3	6	0	2.67

Table 3: Students' answers about motivation and learning during the game session mapped to the points received in an exam question about sorting algorithms.

Feedback given	Fully disagree		Somewhat disagree		Somewhat agree		Fully agree	
Exam question points	Mean	N	Mean	N	Mean	N	Mean	N
1. I learnt new things during the game session.	-	0	4.7	3	6.1	18	5.9	12
2. Playing confirmed things I knew beforehand.	-	0	5.5	4	6.1	19	5.7	10
3. Playing raised questions about course topics.	-	0	-	0	5.5	17	6.3	16
4. Playing is motivating way to discuss course topics.	-	0	5	5	5.8	15	6.3	13
5. It was beneficial to play with others and not e.g. against AI.	-	0	5.5	2	5.7	7	6.0	24
6. I am interested in playing more these kind of games.	7	1	5.7	6	5.8	20	6.2	6

games in teaching. It encourages us to improve the games and the concept for the next year's course. Based on the observations during the game session and the feedback, we will develop the games further. Our aim is also to develop different games to cover more CS topics.

Game sessions were now held separately from other teaching. There are also other possibilities how these kind of games could be used. For example, each game could be integrated to a lab session that deals with the same learning goals than the game. Another approach could be to offer games as independent study material. Students could play the games without an organized game session or a lab exercise. That kind of approach would take into account the fact that not all students are equally motivated by games. One way to utilize the games could also be to implement a virtual learning environment where the games could be played online.

In this case study, the results of the game session limits to the feedback given by the students. It would be interesting to evaluate the learning results of playing these kind of games. This could be achieved, for example, by dividing students into game group and control group and comparing the learning results. The use of games could be broaden out to the non CS major students who take a similar course. The total number of students participating in our data structures and algorithms course is 300-400.

5. DISCUSSION

Based on our experiences of the game sessions, it seems that using these kind of card games can be useful in Data Structures and Algorithms teaching. However, there are room for improvements in the games and the course arrangements. Based on the feedback collected from the students, the rules of the games will be modified for the next year's course.

The use of games in teaching is balancing with the educational content and the entertaining aspect of the game. The challenge is to provide enough entertainment for students to get motivated, but also include decent learning objects for the games. Learning how to play a game takes time that could be used to actually study the course content. Creating games that are quick to learn, but offer profound learning goals is a really challenge.

Based on the feedback results presented in Section 4, the students in advanced programming course did not benefit from the games as much as the other students. This raises a question that do students with less preliminary knowledge benefit more from these particular games than more advanced students? Also, differences in students' personal interests towards games leads to the fact that games might not suit all students.

The line between recreational games and serious games is not well defined and one could argue that every game has some concepts or skills that the players will learn. On the other hand, what makes something a game? There are learning environments that are not considered as games, but have some elements that are very typical for games, such as: points, ranking lists and levels.

There are several options of how games could be utilized in the course. Short game sessions could be organized in the lab sessions throughout the course. Games could also be completely voluntary, allowing the students who are not motivated by them to concentrate on other learning methods.

Most of the games used in education are computer games, which are easy to distribute. Also, there are limitations of what the game mechanism can be, when using non-computer games. On the other hand, playing physically in the same place makes discussion easier.

All the games in this pilot had some learning goals from the area of data structures and algorithms. However, playing games can be useful in other ways as well. Getting to

know fellow students in the beginning of the course might help students to collaborate in the studies along the course. Games might also improve generic problem solving skills and group work skills.

As mentioned in Section 2, there is a high need for empirical studies about learning effects of using serious games in CS education. For next year's course, we are planning to evaluate the effects of the games used in the course. However, designing the best method for evaluating the learning effects is not a trivial task. We could use a pre-test/post-test, but then we would probably have to stick with one game session. These games are presumably more efficient, if they are used freely throughout the semester and not just for one 1.5 hours lab session. We could also measure the exam results of a large population to see whether the learning objectives of the games have been fulfilled.

As mentioned before, games can be used in various way in many different contexts. These questions have risen from the game based learning experiment in the Data Structures and Algorithms course, but they can be expanded to consider computing education in general:

- Can games be used efficiently in education, or do they concentrate too much on things that are irrelevant to the learning goals?
- Some students get motivated by games, but others do not. How could this be addressed?
- What makes a system a serious game?
- How should games be integrated to teaching?
- Should we use computer games or non-computer games?
- In addition to learning the course topics, is there any other benefits of playing serious games in a course context?
- How should we evaluate the effects of using serious games?

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