An Educational Game for Teaching Search Algorithms

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Keywords: Educational Game, Gabe-based Learning, Search Algorithms, Algorithm Visualization, Pacman, Game Learning Efficiency.

Abstract: Search algorithms constitute an important topic in the Artificial Intelligence curriculum and are acknowledged by most tutors to be a hard and complex domain for teachers to teach and students to deeply understand. In this paper, we present an educational computer game, designed to teach search algorithms, based on the popular Pacman game. The purpose of the educational Pacman game is to assist students to understand the artificial intelligence topic of search algorithms in an entertaining, interactive and motivating way. During their experience with the game, students can examine the behaviour of various search algorithms and a graphical annotated depiction of them through suitable visualizations. Visualizations can demonstrate the operational functionality of algorithms and are designed in line with the principles of student's active learning. Various learning activities were designed and request students to apply specific search algorithms in various example cases with or without the assistance and feedback of the game. An evaluation study was conducted in real classroom conditions and revealed quite satisfactory results. The results indicate that the educational Pacman game is an effective way to enhance students' engagement and help them to deeper understand the AI search algorithms.

1 INTRODUCTION

Over the past few years, special attention has been focused on the integration of digital technologies and games in education and there is an increased interest in the utilization of games as educational instruments to assist students' learning and teachers' teaching procedures (Wu et al., 2012). More and more educational systems and serious games are developed and utilized by teachers in the context of their courses. The rapid advancement of web and the technological spread of devices like tablets, smartphones and laptops have greatly facilitated the integration of digital games in educational procedures.

Recently, the development and integration of computer games and game based learning approaches in educational procedures has become a significant focus of attention and has attracted the interest of tutors, educational institutes and researchers. In an effort to attract and engage students and enhance the overall efficiency of learning procedures, digital technologies and computer educational games are examined to add fun factors and make teaching more attractive and appealing (Mihail et al., 2013). In our days, a great part of the students, like most individuals, spend a large part of their free time playing computer games and in this line, the integration of games into courses curriculum could increase students' interest and stimulation and provide opportunities for learning in an entertaining way.

Computer games can be used to teach almost every area of computer science and researchers point out that they could constitute an effective way to provide more interesting learning environments for knowledge acquisition and construction (Sung and Hwang, 2013). Computer games have been used successfully in both introductory computer science courses (Parberry et al. 2005, Bayliss 2007) and general artificial intelligence classes (Wong et al., 2010; Taylor, 2011; Sosnowski et al., 2013; DeNero and Klein, 2010) to scaffold learning and bring excitement and enthusiasm among students. Indeed, through games students are given motives to increase their interest and teachers to implement the learning by doing or by participating principle (Papastergiou, 2009). So, the students have a framework for better grasping or understanding computer science and artificial intelligence concepts.

In an Artificial Intelligence (AI) curriculum, a fundamental topic is the domain of search

Grivokostopoulou, F., Perikos, I. and Hatzilygeroudis, I.
An Educational Game for Teaching Search Algorithms.
In *Proceedings of the 8th International Conference on Computer Supported Education (CSEDU 2016) - Volume 2*, pages 129-136
ISBN: 978-989-758-179-3

algorithms and it is a part of almost any introductory artificial intelligence and computer science course and textbook (Russell and Norvig, 2003). It is vital for students to get a strong understanding of the way search algorithms work and also of their application to various problems. However search algorithms, including blind and heuristic search algorithms, are considered to be challenging for the tutors to effectively teach and students to deeply understand. Specifically, from a tutors' perspective, teaching and explaining how search algorithms operate is challenging and in general requires a lot of explanations, illustrations and teaching aids other than blackboard to assist students in understanding algorithms better (Baecker, 1998). In addition, from a learners' perspective, the algorithms constitute a very challenging task for students to deeply comprehend as they usually model complicated concepts and also refer to abstract mathematical notions (Shabanah et al., 2010). When students learn new abstract concepts such as algorithm heuristics, it can be hard for them without appropriate connection to concrete examples (Ma et al., 2014). Visualization of their functionality and the interactive application in various exercises and learning activities can help students connect abstract concepts and procedures to concrete experiences and examples. Furthermore, learners can recognize and comprehend virtual graphical representations faster and deeper than textual instructions and static representations (Shabanah et al., 2010).

In this paper, we present an educational computer game that is based on the famous Pacman game. The purpose of the educational Pacman game is to assist students to understand the artificial intelligence search algorithms in an entertaining, interactive and motivating way. During their interaction with the game, students can see the behavior of search algorithms and graphical annotated depictions of them through algorithm visualizations. Visualizations can demonstrate the operational functionality of algorithms and are designed in line with the principles of student's active learning. Various learning activities were designed that instruct students to apply specific search algorithms in various example cases with or without the assistance and feedback of the game. An extended evaluation study was conducted in real classroom conditions and revealed quite satisfactory results. The results indicate that the educational Pacman game is an effective way to enhance students' motivation and help them to deeper understand the AI search algorithms. In addition, the game can benefit students' learning motivation and also assist them get a deeper understanding of search algorithm functionality.

The structure of the rest of this paper is as follows: In Section 2, related work on the utilization of games in teaching concepts of Artificial Intelligence and Computer Science are presented. In Section 3, we present a game to assist students in learning search algorithms. In Section 4, the evaluation study conducted and the results collected are presented. Finally, Section 5 concludes the paper and provides directions for future work.

2 GAMES FOR TEACHING AI

In recent years, the design and integration of games in education and courses curriculum have attracted the attention of researchers. A detailed and complete overview of approaches can be found in (Michael and Chen, 2005; Connolly et al., 2012; De Gloria et al., 2014; Gibson and Bell, 2013).

In literature, there is great research interest and many works study the design of educational procedures and the development of games for teaching the domain of computer science. In (Levitin and Papalaskari, 2002), the authors present the using of the puzzles in teaching design and analysis of algorithms. In (Markov et al., 2006), authors presents a work that uses machine learning as a theme to unify core AI topics typically covered in the AI course using the N-puzzle game and provides several pedagogical possibilities for the game. In (Sosnowski et al., 2013), authors present SEPIA which stand for Strategy Engine for Programming Intelligent Agents and is a game environment for AI teaching. SEPIA is based on a real-time strategy game, modified extensively to preferentially support the development of artificial agents. Another effort is presented in (Chang et al., 2008) where a game-based learning approach is used to help students learn graph theory topics and more specifically Kruskal's, Prim's and Dijkstra's algorithms. The game is called Ticket to Ride and the students through the missions that they choose about connecting one city to another, come across the implementation of the above algorithms.

In (Hatzilygeroudis et al., 2012), authors present an educational game to assist students in understanding the Constraint Satisfaction algorithms. The game aims to offer an entertaining, interactive and most of all motivating way to students to experience with and learn about aspects of constraint satisfaction problems, constraint propagation and algorithms for constant consistency.

Robocode (Hartness, 2004) is a programming Java game where the goal is to develop a robot battle tank to battle against other tanks programmed by other players. It is designed to help students to learn Java programming and used into an artificial intelligence class to provide students tools for developing practical versions of algorithms. Moreover, the robot battles are running in real-time and are suitable to all kind of programmers from beginners to experts. In the work presented in (Eagle and Barnes, 2008), authors introduce the Wu's Castle game that is a two dimensional role playing game teaching loops and arrays in an interactive, visual way. The game provides to the students immediate feedback and helps them visualize the execution of their code in a safe environment.

3 TEACHING AI ALGORITHMS VIA A GAME

3.1 Learning Objectives

The learning objective of the game has an educational goal and it aims to assist and to motivate students to learn and deeper understand AI search Algorithm. In our game, several learning activities were designed to offer students various opportunities to study and examine the way that search algorithms operate and the learning activities are based on the revision of bloom taxonomy.

The Bloom Taxonomy (Bloom, 1956) is a classification of different levels of cognitive learning objectives that tutors can set for students. It is an important instrument in designing teaching procedures that can provide a detailed understanding of the learning objectives and can also help to design activities based on the learning goals. For the learning objectives of the game, the Bloom's Revised Taxonomy (Anderson et al., 2001) was utilized. It describes six progressive levels of learning, which are starting from the foundation towards the pinnacle and are the following: Remembering, Understanding, Applying, Analyzing, Evaluating, Creating.

Initially, regarding the theoretical aspects of the search algorithms domain, the game can present basic background topics and the description of the algorithms. Specifically, it presents the basic textual description of algorithms and their corresponding graphical flowchart along with their pseudocode. The aim is to assist students in studying and constructing their knowledge. The playing process mainly requires of students to apply their knowledge of the algorithms in specific scenarios in our educational Pacman game. During the game playing, students need to analyze a specific algorithm selected to study into its main sub-steps and specify correctly the next moves. Also, the students can select a specific algorithm to study and the theoretical topics are presented to illustrate the way the algorithm operates. Finally, evaluating the students engage in checking and critiquing the incorrect selection and it helps the student think about why they have made an incorrect choice.

3.2 Design of the Game

The design of the game was based on the popular Pacman game and was developed by our university team using Java programming language. The game is a one player game that the students can study, examine and implement the blind and heuristic search algorithms in various maze scenarios. The game consists of two main modes that are the "Educational mode" and the "Playing mode" and the starting menu of the game is illustrated in Figure 1.

Figure 1: The main game modes of the game.

In the educational mode, the student can select the type of the algorithm to study and the game can present textual description of the algorithm and the graphical flowchart along with its pseudocode. The game offers the student the opportunity to study the algorithm via visualizations and in this approach the game illustrates the functionality of the algorithm in example mazes of Pacman. Thus, students can study the theoretical aspects of an algorithm in line with appropriate explanations and algorithm visualizations on various Pacman mazes.

Algorithm visualizations and animations are well pointed to assist students in learning algorithms (Hundhausen et al., 2002). Indeed, the visualizations, when used properly in a learning process, can help a student deeper understand the way that an algorithm operates, by demonstrating how it works and how it makes proper decisions

based on parameters, such as heuristic and cost functions (Hansen et al., 2002; Naps et al., 2002). In the game, during the visualization of an algorithm, every decision that the algorithm makes, such as for example which node(s) to expand/visit, is properly presented and explained to the student. The Pacman game explains how a decision was made by the algorithm and how the values of the parameters, such as the heuristic and the cost functions (if any), were calculated for each algorithm's step. Although visualizations are utilized in various systems and games, they are in most cases integrated without aspects and opportunities to engage and interact with students during the animation process (Shabanah et al., 2010). In the game, a noticeable aspect of algorithm visualizations is that they have been developed according to the essence of student active learning. More specifically, the visualizations have been designed based on the principle of engaging the student as much as possible in the demonstration process and making student to think hard at every step of the algorithm's animation. The principles of active learning maintain that the more the users directly manipulate and act upon the learning material, the higher the mental efforts and psychological involvement and therefore the better the learning outcome (Lee and Rößling, 2010).

In this spirit, during an animation demonstrating the implementation of an algorithm in a maze, the game and the Pacman can stop at a random step of the algorithm and ask the student to specify some aspects regarding the operation of the algorithm. The animation may engage the student and request from him/her to specify the next grid position on the maze to be visited or ask him/her to justify why a movement was made. In general, such justifications mainly concern either the last action (or actions) conducted by the Pacman simulating the algorithm or the specification and proper justification of the next action to be conducted. The interaction with the student and the questions asked are either interactive questions or multiple choice questions. The interactive exercises may require of the student to interact with Pacman in the maze and specify the next movement based on the algorithm's step. For example, during visualization the Pacman can pause and ask the student to specify the next algorithm's step by selecting the proper next grid position. In case of a correct student's answer, it can also request from student to justify the reason, by offering additional multiple choice question(s). In case of an erroneous answer, knowledge of correct response and proper explanations are immediately offered to the student. After an interaction with the learner, the animation process continues. In this line, during an algorithm's visualization in an example exercise scenario, multiple interactions with the learner can be made.

As an example, consider the simple case depicted in Figure 2 where the visualization demonstrates the operation of the breadth search algorithm in a case where the aim is for Pacman to reach the cherries in the maze starting from the default position. The visualization has paused just after the first movement of the algorithm and asks student to specify the grid to be visited by Pacman based on the algorithm. The student can either click on the grid or move the Pacman with the keyboard.

Figure 2: An example visualization.

Additionally, the game provides students the capability to select the type of algorithm and then to see the application of it on the maze with the additional explanations and information at the steps of the algorithms such as heuristic functions, cost calculated and other. For example, Figure 3 presents the application of Depth-First algorithm as implemented by the Pacman in order to get the power-up in the bottom-left corner starting from the default starting position. The corresponding tree representation is presented in an expletory window.

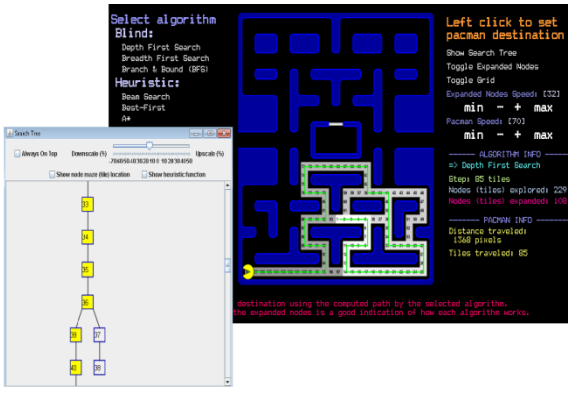

Figure 3: Depth-First Algorithm in PacMan.

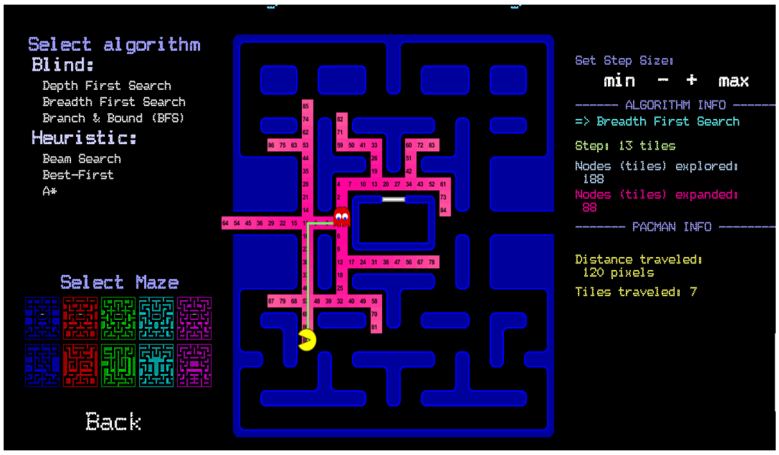

Figure 4: Experimental procedure of the Pacman Game.

The graph represents the maze and the way that the Pacman moved in it. The nodes of the graph are the tiles of the maze and the additional information like heuristic and cost are illustrated on the graph to help students to understand how movement decisions were made.

Furthermore, the game provides various demonstrations of how a ghost agent can move in a move according to a specific algorithm. Specifically, the game can highlight aspects of how a ghost 'operates' according to a specific algorithm and moves in the maze. For example, in Figure 4, the way that a ghost operates and is moving is illustrated. The ghosts are generally aiming to reach the Pacman and then the game ends. The student can move the Pacman in the maze to collect the dots and evade the ghosts and can observe, while Pacman is moving, the way that the ghost applies a specific algorithm and how is examining the maze tiles and it decides to move. In this spirit, in every state the maze's tiles that are expanded and are in the open list of the algorithm, are highlighted with purple background. The green line between the Pacman and the ghost highlights the shortest path between them. The game illustrates in every state the distance in tiles between the ghost and the Pacman and also the number of tiles that the ghost and the algorithm has explored and has expanded. In the example state presentend in Figure 4, the ghost has explored 188 tiles, has expanded 88 tiles and the distance between the Pacman and the ghost is 13 tiles.

The second game mode of the game, as mentioned above, is the "playing mode". It is designed to be more challenging and fun oriented. In this mode, the student has to solve predetermined maze levels of Pacman under different conditions and in a specific amount of time, something that can make the playing mode more challenging and motivating. Also, in this mode students can complete maze levels and proceed to next ones that are more complex and challenging in a similar manner like in the original version of the Pacman game. The various levels are designed in the spirit to necessitate students to apply a specific search algorithm and properly move the Pacman in the maze in order to accomplish the level requirements. The level requirements in general concern Pacman to reach in the maze a specific fruit, a power-up and also eat dots. In this approach, the student is requested in a maze level, starting from a random position, to reach the goal (e.g. a cheery or a power-up) by moving Pacman based on the specific algorithm that the level specifies. The student using the keyboard can move the Pacman in the maze and specify the direction to follow. In case of an incorrect movement, the ghosts that are in the maze can move faster towards to Pacman. The only case for the student to complete the level is to correctly apply the algorithm and properly move the Pacman in the maze towards the goal(s). As the student proceeds, next levels are getting more complex in terms of maze characteristics, number of ghosts in the maze, goals to achieve and most of all, the complexity of the algorithm and its parameters that are requested from student to apply.

4 EVALUATION

The purpose of the study is to examine the efficiency, the motivation and the effectiveness of the educational Pacman game in learning of AI search algorithms. We conducted an evaluation study for the educational Pacman game during the

Artificial Intelligence course at our department. The participants of this study were 38 students (male and female) from those enrolled in the Artificial Intelligence course. Initially, all the students were randomly divided into two groups of 19 students each, namely experimental group (EG) and control group (CG). The two groups consist of almost the same number of girls and boys. Also, we used a pre-test, a post-test study and a questionnaire survey for measuring the learning effectiveness, the learning attitudes and the motivation from using the Pacman game in the context of Artificial intelligence course in our department. The experimental procedure used to evaluate the game is illustrated in Figure 5.

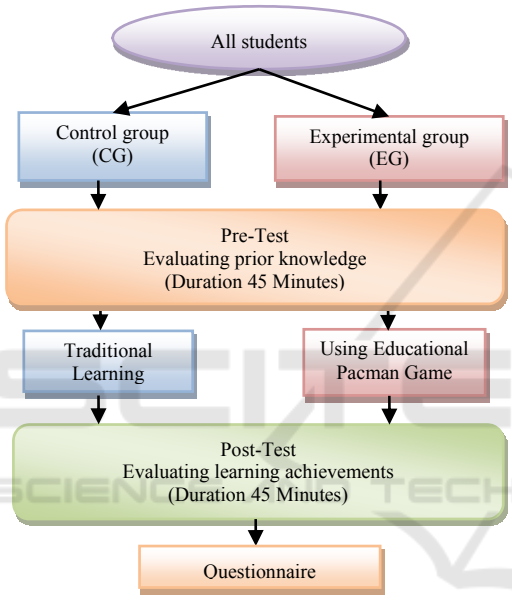

Figure 5: Experimental procedure of the Pacman Game.

All the students took a pre-test to evaluate the prior knowledge on AI search algorithms. The pre-test aimed to ensure that the groups had equivalent prior knowledge on AI search Algorithms. The pretest consisted of twelve questions on the AI algorithms and the duration of the pretest was 45 minutes. Then, all the pretests were marked by an expert-tutor and the score of the test ranged from 0 to 10 points.

After that, the experimental group interacted with the Pacman game for two weeks and the control group was selected to study the lectures and discuss with the teacher. Then, all the students took a post-test. The purpose of the post-test was to evaluate the learning performance and achievement of the students after the participation in the learning activities. The post-test consisted of twelve exercises of the same difficulty levels with those in pre-test and the students were given 45 minutes to complete the test and submit their answers. After the learning activities the students were asked to fill in a questionnaire and express their feelings and opinions towards the game and assess its learning assistance.

4.1 Evaluation Results

Initially, a one-way Analysis of Variance (ANOVA) was performed on the pretest. The means of pre-test for Control Group (CG) and Experimental group (EG) were 3.63 and 3.72 respectively. The results showed no significant difference among the students of the groups ($p=0.648 > 0.05$, $F=0.212$) so it is concluded the two groups had equivalent prior knowledge before using the game. Then, we conducted an Analysis of Covariance (ANCOVA) to extract the difference between the two groups using the pre-test scores as the covariate and the post-test scores as dependent variables. Table 1 summarizes the descriptive statistics for the post-test conducted. The ANCOVA results indicate the differences in post-test scores are statistically and significantly different between the two groups ($F=83.143$ $p=0.00<0.05$). Finally, the results showed that the performance of the students of experimental group, who used the Pacman game, was better than that of control group.

Table 1: Post test Results.

Groups	N	Mean	SD
Control Group (CG)	19	4.605	0.698
Experimental Group (EG)	19	6.861	0.782

Then, the students of the experimental group were asked to fill in a questionnaire including questions for evaluating usability of the game, stating their experience and their opinions about the learning impact of the game in teaching search algorithms. The questionnaire included 15 questions. The questions Q1-Q12 were based on the Likert scale (1: not at all, 5: very much). Questions 13-15 were open type questions and concerned strong and weak points of the game or problems faced and also improvements that can be made to the game.

After analyzing the students' responses to the questionnaire, the reliability of the questionnaire was checked using the Cronbach's alpha (Cronbach 1951) metric. The reliability of the scale was good and the internal consistency coefficient was 0.87.

The questionnaire results indicate that the students' feeling about the game was very positive, as summarized in Table 2. Results point out that the

Table 2: Questionnaire Results.

Q	QUESTIONS	ANSWERS (%)				
		1	2	3	4	5
1	I enjoyed playing the game	0	0	0	5.3	94.7
2	The interface of the game is easy to use.	0	0	0	10.5	89.5
3	The game made me more active in the course	0	0	0	21.0	78.9
4	The game can increase my motivation	0	0	10.5	10.5	78.9
5	The game can enhance my engagement in the course.	0	0	5.3	15.8	78.9
6	The game can enhance my learning interest.	0	0	5.3	15.8	78.9
7	The using of the game for learning is more interesting than other ways of learning.	0	0	0	10.5	89.5
8	The game assisted me in learning more effectively the search algorithms.	0	0	0	5.3	94.7
9	The game assisted me in getting a deeper understanding of the functionality of the algorithms after playing.	0	0	5.3	10.5	84.2
10	The interaction with the visualizations of the algorithms assisted me in understanding the algorithm way of function.	0	0	0	10.5	89.5
11	Using the game provides me with new way of thinking about AI search algorithms	0	0	0	10.5	89.5
12	Will you recommend the educational game to other classmates and be integrated in the course curriculum?	0	0	5.3	10.5	84.2

majority of the students greatly enjoyed studying and playing with the game (94.7%) and a considerable portion of them (89.5%) found the interface of the game easy to use. Also, (78.9%) of the students indicated that the game is more interesting that other educational approaches and ways of learning (89.5%). In addition, a great portion of the students stated the game increased their motivation (78.9%), engagement (78.9%) and interest (78.9%) and made them more active in the course (78.9%). Regarding the learning efficiency of the game, students stated that the game helped them in learning more effectively (94.7%) and in getting a deeper understanding of the algorithms (84.2%) after playing. In addition, the interactions with the game during the algorithm visualization assisted students to understand the way an algorithm function (89.5%). In general, the results showed that the game assisted the students to get a deeper understanding of the AI search algorithms and the way they operate in an entertaining way. Moreover, approximately (89.5%) of the students stated that the game can provide them a new way of thinking about AI search algorithms. Finally, the majority of students (84.2%) suggested the game to be integrated in the course curriculum and be used by the next year students.

5 CONCLUSIONS

The educational games can offer various possibilities for learning. In this paper we present an educational computer game based on Pacman that aims to assist the students to learn the artificial intelligence search algorithms in an entertaining, interactive and motivating way. During the game, students can observe the behaviour of the search algorithms and graphical annotated depictions of them, through algorithm visualizations. Visualizations can demonstrate the operational functionality of algorithms and are designed in line with the principles of student's active learning. Various learning activities require of students to apply specific search algorithms in various example cases with or without the assistance and the feedback of the game. An extended evaluation study was conducted in real classroom conditions and revealed quite promising results. The results indicate that the educational Pacman game is an effective way to enhance students' motivation and help them to deeper understand AI search algorithms.

As future work, a bigger scale evaluation will be designed to provide a more complete insight of the learning efficiency of the game and also evaluate specific educational capabilities such as the feedback and assistance offered to learners. Furthermore, a learning analytics module will be developed to record students learning actions while playing and analyse them with the aim to extract knowledge from them. Exploring this direction is a key aspect of our future work.

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