A Location-Based Educational Game for Understanding the Traveling Salesman Problem - A Case Study

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Abstract
Due to the high potential of digital media to support learning processes and outcomes, educational games have gained wide acceptance over the years. The combination of mobile devices with location-based technologies offers new options and possibilities for the development of educational games in consideration of learners' environment with the positive side effect to promote learner's physical activities. This paper introduces a mobile educational game for promoting a better understanding of concepts related to route problems and route optimization on the basis of real world examples in a playful manner. The game combines problem-solving tasks with a quiz to teach concepts related to the Traveling Salesman Problem (TSP) by using the Global Positioning System (GPS) technology.

Author Keywords
Game-Based Learning; Location-Based Game; Traveling Salesman Problem; Global Positioning System

ACM Classification Keywords
K.8.0 [General]: Games.

Introduction
The understanding and use of *abstract concepts* are skills that are fundamental in education and many other areas of life. Still, learning is not always an easy task and fre-

Figure 1: An example of a graph superimposed on a geographical map with nodes A, B, C, D, E, and F. Edges show the direct paths between the locations. The edge weight corresponds to the distance (measured in meters) between the locations. The red path shows the shortest route between A and G with respect to the total distance covered. Map data ©2016 Google

quently learners struggle particularly with such abstract learning content (cf. [19]). To address this learning difficulty, researchers and educators attempt to find alternative teaching methods to break through the traditional lecture format where learners are passively sitting in classrooms; various approaches to teaching and learning have emerged. Giving learning settings a playful touch has proven beneficial for people's motivation to learn and also for improved learning outcomes (cf. [7, 21]). And so it is no coincidence that educational games have a long history, as those facilitate learning for children and adults alike [22]. Integrating multimedia elements – such as animation and games – have been shown to offer new ways for learning and motivate learners positively (e.g., [11, 17, 27, 29]). Furthermore, media allow for didactical approaches that would not be possible in pure traditional learning settings [1].

In this paper, we focus on the Traveling Salesman Problem (TSP). Adding location tracking technologies and sensors as well as game characters to teach such abstract concepts and problems may provide a promising foundation for learning these in a less abstract and more engaging way. Furthermore, due to the success of mobile games, such as Pokemon GO [23], which already successfully showed the potential of combining mobile devices with location-based technologies to support physical activities in a playful manner, we assumed that this combination can also be used to motivate learners to engage them with the subject matter. Moreover, it has been shown that physical movement can support learners to assimilate information (cf. [14]). The TSP concepts we are dealing with seem especially suitable for such an approach as it provides a certain real-world context. In this paper, we thus present a mobile educational game which makes uses of the Global Positioning System (GPS) technology to support learners in understanding concepts related to TSP. The game was developed to provide an improved learning experience for learners who have little previous knowledge about route problems and route optimization. Furthermore, the user interface and the interaction design influence the usability of a game and are thus key factors how well players can control and understand the game. A game with a hard to understand user interface and interaction design can have a negative impact on the motivation to play the game and can influence the learning process. Therefore, it is important that the usability of the game does not interfere with the underlying educational goals. We discuss preliminary results of an evaluation with respect to the playability and usability of the game as well as the learning outcomes. For the evaluation of the game, methods from Human-Computer Interaction (HCI) have been adapted.

Background and Related Work

Approaches to Learning

Literature knows many approaches and theories about how learning emerges and changes. Most of them give their own notions of what learning is and how it can and should be initiated and supported [1]. The various approaches come down to one perspective in acknowledging that learning takes place inside a person and it cannot be forced, ordered, or fulfilled by others [28, p. 288]. Still, it is possible to facilitate learning processes by providing conditions and resources that are – according to Tausch and Tausch [28, pp. 288–289] – most valuable if they are manifold, inciting, and available for autonomous exploration and usage, and close to reality. Especially for rather abstract learning content it is challenging – though at the same time necessary – to give meaning to the learning problems and to get them as close to real-world problems as possible. Thereby, it has been proven beneficial to give the learning setting a playful touch, as it increases motivation and improves learning outcomes [21]. Educational games, though, are

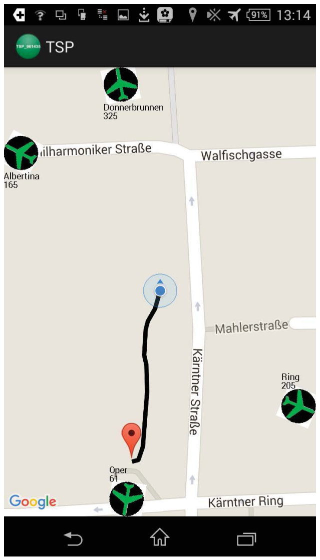

Figure 2: An example of a player's movement (black line). Red markers represent the locations, the blue icon shows the player's position, and the airplane icons represent the direction in which the locations lie as well as the linear distance between the player's position and the locations. Map data ©2016 Google

not an invention of present times but have existed for a long time; ever since they facilitate learning for both, children and adults [22]. Using computers and the Internet for (re)search tasks and providing learning content with various presentation media (e.g., text, audio, video, animation, etc.) are the mainly used approaches to integrate media into learning settings. Still, applications for all purposes have turned the smartphone (and similar mobile devices) into a multi-functional device that pervades everyday life [16]. Equipped with various sensors, such mobile devices are an interesting resource for educational games (e.g., [9]). Beside that, mobile devices offer learners flexible access and supplemental learning materials making mobile learning increasingly attractive (e.g., [5, 20]). For supporting the understanding of TSP, we are particularly interested in the integrated location-based technologies, which can be considered standard components in today's smartphones.

GPS and TSP Games

Literature and the existing variety of available apps have shown that Global Positioning System (GPS) is a promising localization approach for everyday applications (e.g., [2]). Also several educational games for smartphones take a GPS approach. For instance, some apps use GPS data in a playful context (see, e.g., Geocaching [4, 12]) or for analyzing routes (e.g., GPSies Android [3]). Several mobile applications were developed for supporting learners to understand the fundamentals of TSP. While, for instance, Bebras [10] aims at improving the knowledge transfer in education, other apps focus on aiding the understanding TSP in particular (e.g., Salesman Challenge [24], Traveling Salesman [8], or Traveling Salesman Game [25]). However none of these mobile approaches combines the concepts related to TSP with location-based technologies to motivate learners to understand the concepts with the help of real world examples.

Game Design

The goal of the introduced mobile educational game for understanding the TSP is to support learners who have little previous knowledge about route problems and route optimization in understanding the concepts related to the TSP in a playful manner. The design emphasizes two aspects: (i) help learners identify the shortest path between a set of vertices; and (ii) understand that the order of the vertices plays a role in finding the shortest path. In our game design, players have to walk between predefined locations in the real world to define a route; thereby the GPS technology of the learner's mobile device is used to track the route. Out of the localization technologies integrated in standard mobile devices, the GPS approach is considered the most suitable candidate for our TSP learning setting: (a) it is worldwide available [18]; (b) it does not need additional infrastructure [13]; and (c) it works – despite some imprecision due to external influences – on a rather fine-grained basis [2]. The map can be described as a graph where the locations on the geographical map represent the nodes and the edges represent the path between the locations. The weight of each edge of the graph is calculated by the distance covered in meters between the locations. For example, Figure 1 shows a graph superimposed on a geographical map. The graph consists of seven nodes and eight edges with the following distances (weights): AB = 66, BC = 100, BE = 53, CD = 83, DE = 100, DG = 50, EF = 71, and FG = 110. Supposing the start location is node A and the end location is node G, then the shortest path is $A{\to}B{\to}E{\to}D{\to}G$ with the total distance covered of 269 meters (AB + BE + DE + DG).

The basic idea behind the game is to combine the identification of routes between predefined locations in the real world (problem-solving tasks) with a quiz (factual questions) (in consideration of Gee's [11] learning principles):

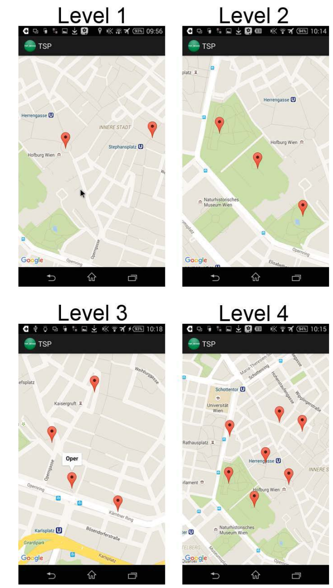

Figure 3: The predefined locations which the players have to visit in each level. Map data ©2016 Google

Problem-solving tasks. The players have to find routes between predefined locations on a geographical map. The locations on the map are represented by red markers and a blue icon represents the position of the player (see Figure 2). For better orientation, airplane icons show the direction in which the locations lie and the linear distance between a player's position and the positions of the locations. The location that the player visits first is defined as start location and the tracking of the player's movements starts. The player's movements are visualized as lines on the map. The first version of the game focuses on Vienna and attractive locations that are easily accessible within this city. Players start with a simple task to familiarize with the impact of route decisions. Then the tasks (in four levels) become progressively more challenging and complex to support the participants understand the TSP:

Level 1: In this level, the players have to find the shortest route between two predefined locations, whereby they can select which of the two locations is the start location and which one is the end location (see Figure 3, Level 1). The main goal is to help players familiarize with the game and the impact of route decisions: Players learn how they can connect the predefined locations by walking from one location to the other and how the locations as well as movements are visualized. The main learning is to see how the total distance covered may change depending on route decisions.

Level 2: In the second level, the players have to find the shortest path between three predefined locations (see Figure 3, Level 2). The goal is to support players in developing an understanding of the Hamiltonian Path Problem which forms the foundation for understanding the TSP. The main learning is that the selection of the start location plays an important role for finding the optimal route between the locations.

Level 3: In the third level, players have to find the shortest route that visits four predefined locations with the additional condition that the start location is also the end location of the route (see Figure 3, Level 3). This level aims at supporting players develop an understanding of the Hamiltonian Cycle which is a further important foundation for the understanding the TSP. The main learning is that the selection of the start location does not play a role in this context.

Level 4: In the fourth level, the players have to find the shortest route between seven predefined locations (see Figure 3, Level 4). The goal is that players understand the importance of the order in which they visit the locations to optimize their route. Based on the learning from the other three levels, this level aims at supporting learners in understanding the TSP.

Quiz. After each level, the players have to play a quiz in order to unlock the next level. The goal of the quiz is that players reflect on what they have learned in the previous levels and are able to answer a set of factual questions on their newly acquired knowledge. Furthermore, the quiz should encourage the players to engage with the underlying concepts of the previously played levels. It also offers further readings about the subject matter, which may be helpful for answering the questions correctly.

In addition, the game includes a high-score table for each level which ranks first in the list the players who had the shortest total distance covered. This should encourage friendly competition among the players. Players can only see the high-score tables of their unlocked levels. Furthermore, players can also analyze their played routes and

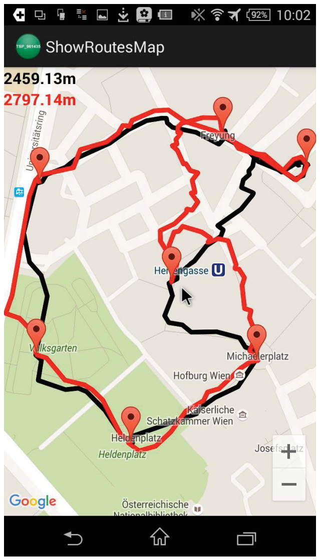

Figure 4: An example of the comparison visualization of two routes (red and black) for the same level. Map data ©2016 Google

compare them on the map. Figure 4 shows two different routes for the same level. Each route is visualized as a line with an individual color together with the total distance covered in meters. The comparison of the routes enables players to analyze and optimize their routes in order to find a shorter path between the locations.

Design Process

For the development of the game, we applied the Human-Centered Design process [15] – an iterative design process which was originally for interactive systems. We used this design process to ensure a user-friendly design of the game in order to convey the underlying educational goals and to foster the learning outcomes. As of this writing, the development of the game required two iteration cycles. The iterative process helped us to continually refine the design of the game based on feedback from players and an HCI expert familiar with game design (cf.[6]). In the first iteration phase, the focus was on the analysis of literature, existing mobile applications, defining requirements, and analyzing how these requirements can be realized. Furthermore, low-fidelity prototypes and storyboards were created to explore different design ideas. The different design concepts and how the requirements can be realized were discussed with an HCI expert. Based on the expert feedback, the game was implemented for Android phones in the second iteration phase. The first version of the game includes four different difficulty levels. In order to get preliminary feedback from players, the game was evaluated with eight persons.

Evaluation

In order to receive first feedback from learners, the game was evaluated in a user study with eight participants (4 female and 4 male participants) between 14 and 60 years. All participants had only little previous knowledge about route problems and route optimization. The evaluation focused on the learning outcomes and game design components (in particular, the usability and understandability for players).

Procedure. The procedure consists of four steps. First, the participants had to fill in a questionnaire about demographic data. In this context, they were also asked about their experience with game-based learning and geocaching. Furthermore, participants had to perform a small task allowing us to assess their ability to solve tasks related to the optimal path, the Hamiltonian Path/Cycle and the TSP. Second, the participants played the game for approximately one week. This length of testing period was chosen to give the participants the possibility to get acquainted with the game and provide them with the opportunity to follow the routes. In the third step of the evaluation procedure were conducted semi-structured interviews. In these interviews, we assessed the participants' subjective attitude towards the game. Finally, we assessed the participants' ability to solve the optimal path, the Hamiltonian Path/Cycle and the TSP again. Interview sessions took about 50 minutes. Responses to open-ended questions and interviews were analyzed using qualitative content analysis [26].

Results. The pre-game and post-game comparison (see Table 1) of the participants' solutions to the Hamiltonian Path/Cycle and the TSP tasks indicated a slight improvement in the outcomes (i.e., more correct solutions). A detailed analysis of the participants' results to the assignments revealed that even the solutions that were not entirely correct have been better than before playing the game. Due to the low number of participants, this improvement is only an indication that playing the game might have a beneficial impact on the learning outcomes. Further in-depth research with a large-scale sample is necessary. In the qualitative interviews, the participants mentioned that the game helped them to feel more confident with the ad-

Task	Pre		Post	
	Correct	Incorrect	Correct	Incorrect
Optimal Path	8	0	7	1
Hamiltonian Path/Cycle	5	3	7	1
Traveling Salesman Problem	4	4	5	3

Table 1: Number of correct and incorrect answers related to the optimal path, the Hamiltonian Path/Cycle and the Traveling Salesman Problem before and after playing the game.

dressed kind of problems. They also found that they had learned a lot about how GPS works and how route planning should be done. The questions asked during the tests were found to be challenging by the participants, but they could still solve them in the end. We could observe that they had difficulties to understand some of the icons at first, but they learned their meaning easily. The high-score tables were mentioned as motivating, because it allowed them to compare their achievements with others. Furthermore, they liked the concept of levels and found it easy to understand how one level follows the other and they enjoyed looking at the visualization of the routes they took. However, they had also some concerns. For example, they mentioned that it was boring to revisit the same locations several times or to follow the routes was a time-consuming activity. There were controversial results as far as the quality of GPS tracking was concerned. 5 participants found this to be good, the other 3 were more critical. 5 of the participants noticed that there were obvious outliers due to the inaccuracy of the GPS tracking.

Discussion

In general, the preliminary results of our evaluation have shown that the game was well received by the learners. The results of the evaluation indicate that the game proposed in this paper can help learners to get acquainted with the Hamiltonian Path/Cycle and TSP which may suggest that physical activities can support learners to assimilate information. On the one hand, participants' achievements were improved after the game. On the other hand, the participants mentioned that they enjoyed the game and that they got the impression that they know more about route finding after having played the game. The structure of the game, especially the different levels with gradually increasing complexity, were found to be attractive and motivating. Nevertheless, the participants also mentioned some drawbacks. They especially criticized the routes that led them to the same locations of interest on the different levels. Some participants also complained that the routes were too long. Accordingly, they made some suggestions to improve the routes (e.g., allowing players to add their own locations). One major problem was the inaccuracy of GPS. Participants noticed that the same location of interest could be found at different locations on different levels. The deviation can measure up to several meters. One consequence of this is that the game presents impossible routes on the screen. These routes can lead through the middle of a house or deviate considerably from the actual route taken by the game player (see, e.g., Figures 2 and 4). Another consequence of this inaccuracy is that it is difficult to compare several different routes. To overcome this problem, the Local Positioning System (LPS) technology might be a promising alternative to the GPS technology, especially in areas where GPS reception is weak or non-existent. Further studies that compare LPS and GPS for the game are necessary and a possible direction for future work.

Conclusion and Future Work

The combination of mobile devices with location-based technologies allows us to see new options and possibilities not only for game-based experiences but also for the development of educational games to integrate learners' environment with real world examples. However, investigations are necessary to handle challenges in a user-friendly game design in order to convey the underlying educational goals in consideration of learners' environment. In this paper, we presented a mobile educational game which used a location-based technology to support learners to gain a better understanding of TSP concepts. The preliminary results showed that the selection of locations but also the technology played an important role for the design of such location-based games.

As future work, it is planned to allow players to create and play their own custom routes from a set of predefined GPS coordinates. This can motivate them to return to the game more often, since it enables a never-ending stream of content. Furthermore, we will address the problem of GPS inaccuracy and integrate a solution into the learning game. Further in-depth research with a large-scale sample is necessary. The focus of our first study was on playability and usability of the games, to be sure that the usability of the game does not interfere with the underlying educational goals. As next step a follow-up study is planned to investigate if people learn better the concept of TSP if they walk routes than sitting in classrooms.

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