GAMIFYING MATH TRAILS WITH THE MATHCITYMAP APP: IMPACT OF POINTS AND LEADERBOARD ON INTRINSIC MOTIVATION

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Gamification in education describes the application of game elements in the design of learning processes. The MathCityMap project, which consists of a web portal and a gamified application for smartphones, combines the idea of math trails with the possibilities of mobile devices. To evaluate the impact of points and leaderboard on intrinsic motivation a pilot study has been conducted. The results suggest that there is no significant difference between these two game elements. However, gender seems to play an important role on the impact of gamification on intrinsic motivation.

Keywords: math trails, app, gamification, motivation, gender

INTRODUCTION

The British Department of Education and Skills recommends doing more lessons outside the classroom. Learning outside can “nurture creativity, develop skills, improve attitude to learning, stimulate and improve motivation” just to name a few (DfES, 2006). One suitable way to implement learning outdoors in the math classroom is the math trail concept. The math trail idea was born in Australia in the early 80s (Blane & Clark, 1984). A math trail consists of a set of mathematical outdoor tasks or problems in walking distance. Tasks like “What is the height of the building?” or “How much water is in the pond?” are bound to real objects in the environment and therefore often authentic and motivating. To answer this kind of questions it is necessary for the student to measure (enactive action), to translate the problem into a mathematical model (abstraction) and to calculate the answer (cognitive action). The connection of these three cognitive levels is valuable, because one is more likely to remember the learned later (Rösler, 2011). The trail guide (Shoaf, Pollak & Schneider, 2004) is a booklet, which contains a map that shows mathematically interesting places and the description of the tasks.

Although mobile devices and computers are widely used in every aspect of our daily lives (especially among pupils), they play just a little role in education (Chen & Kinshuk, 2005). Going on a math trail could greatly benefit from using mobile devices, because they allow learning to occur in an authentic context and extend to real environments. At the Goethe-University of Frankfurt / Main we started the MathCityMap Project (MCM), which combines traditional math trails with the opportunities of new technologies. In 2013 first ideas have been made concrete (Ludwig, Jesberg, Weiss, 2013), but it took until 2016 to finally launch a web portal and a mobile application. These are mainly for teachers and their students to use in class, but everyone is free to use it.

In the summer term 2016, we had the opportunity to observe some school classes going on a math trail with the MCM app. Besides many positive observations, we also made two negative observations: (1) answers were often guessed, (2) there is a motivational obstacle to begin working on the tasks (for example expressed in walking slowly to the first task).

THEORETICAL BACKGROUND

Motivation

The most basic distinction in Self-Determination Theory (SDT) is between intrinsic motivation, which refers to doing something because it is inherently interesting or enjoyable, and extrinsic motivation, which refers to doing something because it leads to a separable outcome (Ryan & Deci, 2000). Most activities in school are not inherently interesting and therefore must initially be externally prompted. A person that faces an activity due to external regulations might experience the activity's intrinsically interesting properties, resulting in an orientation shift (Ryan & Deci, 2000). The Intrinsic Motivation Inventories (IMI, 1994) define interest and enjoyment as a central measure of intrinsic motivation. For Ryan & Deci (2000) the source of intrinsically motivated behaviour lies in satisfying psychological needs namely competence, autonomy and relatedness. A higher intrinsic motivation manifests in personal, cognitive, emotional and behavioural engagement (Fredricks, Blumenfeld & Paris, 2004), which are desirable attitudes towards learning.

Gamification

Gamification describes the application of game elements in a non-game context to manipulate the behaviour of users towards a certain goal (Fuchs et al. 2014). The term gamification started to occur more frequently from 2010 mainly in marketing, where gamification is used to increase the customers brand loyalty. Huotari & Hamari (2012) divide gamification into three parts: (1) implementation of game elements in non-game activities, (2) resulting psychological changes and (3) visible changes in the user's behaviour. One main goal of gamification is to modify a serious activity, which is bound to a particular purpose (in our case that could be working on a math trail task), so that it appears more game-like and therefore is more inherently interesting to the user resulting in a higher intrinsic motivation and engagement (Hamari et al. 2014).
Game elements are often different types of feedback on the user's action like points, levels, leaderboards, badges and quests (Zichermann & Cunningham, 2011). Although the gamification concept seems suitable to improve psychological aspects in non-game activities, many projects may fail or will not meet the expectations due to poor understanding of how to design gamification (Morschheuser et al. 2017). This is also the case for gamification in education. Dicheva & Dichev (2015) analysed the outcomes of gamification projects in education in the period July 2014 – June 2015 and conclude:

> […] papers that report positive results are only 24%, while those reporting negative results – 7% and the inconclusive – 49%. Thus from 41 papers only 10 can be considered as evidence of positive effects for gamification in education […] (Dicheva & Dichev, 2015, p. 7).

Prior to implementing game elements, Morschheuser et al. (2017) recommend to analyse the projects target group, the conditions and the inherent activities. The result of the analysis is the definition of goals that gamification should achieve. The next step is to design and implement game elements based on the defined goals. Finally, evaluation and monitoring is useful to make further improvements.

Gamification in math education

"Gamification in education refers to the introduction of game elements and gameful experiences in the design of learning processes" (Dicheva & Dichev, 2015). The number of papers about gamification in education grows: 34 papers in the period January 2010 – June 2014 and 41 papers in the period July 2014 – June 2015.

One example of gamification in math education is Attali & Arieli-Attali (2014) “Gamification in assessment: Do points affect test performance?”. The assessment is based on a mathematical online test with 100 questions from grade six to eight (e.g. fraction addition). Participants were randomly assigned to three groups: (1) control group (no gamification), (2) experimental group 1 and (3) experimental group 2. The experimental group 1 could earn up to 10 points per question depending on the time needed to answer the question, whereas the experimental group 2 could earn up to 10 + 5 points (10 for a correct answer and up to 5 additional points depending on the speed). Results show that “the point manipulation had no effect on the main performance outcome, response accuracy” (Attali & Arieli-Attali, 2014). Whereas the response time decreased significantly, but the effect sizes were small. In addition, no differences between female and male participants were found.

GPS-based applications in math education

Two examples of applications in math education, that already successfully use mobile GPS-data, are Wijers, Jonker & Drijvers (2010), who developed a game which allows students to walk along the shape of geometric objects outside the school, and Sollervall and de la Iglesia, who have developed a GPS-based mobile application for embodiment of geometry (Sollervall & de la Iglesia, 2015).

The MathCityMap project

The intention of the MathCityMap (MCM) project is to automate many steps in the creation of the math trail booklet/guide and to provide a collection of tasks and trails that can be freely used or just viewed to get inspiration for own tasks. Furthermore, it gives users (e.g. groups of pupils) the possibility to go on a math trail more independent by using mobile devices’ GPS functions to find the tasks location, by giving feedback on the users answer and by providing hints in the case that one got stuck at a particular task. The core of the MCM project can be divided into two parts, the MCM web portal and the MCM app.

MCM web portal - www.mathcitymap.eu

The web portal is a math trail management system. After a short registration, the user can view public trails and tasks or create his own tasks and trails by typing in the necessary data (e.g. position, the task itself, the answer, an image of the object etc.) into a form. For every math trail, the math trail booklet can be downloaded as PDF or accessed via the MCM App (see Figure 1). It contains all tasks information, a map overview and a title page.

MCM app for mobile devices

The MCM app allows the user to access math trails created with the web portal. The trail data, such as images and map tiles, can be downloaded to the mobile device. After this procedure, it is possible to use a trail without internet connection (see Figure 2). This design decision minimizes technical issues when using the app without mobile internet or in an area with low connectivity. Furthermore, the app offers an open street map overview for orientation purposes, feedback on the entered answers and a stepped hint system. The hint system has the purpose to enable pupils to solve the tasks independently and additionally has a positive impact on learning performance, learning experience and communication (Franke-Braun, Schmidt-Weigand, Stäudel, & Wodzinski, 2008).

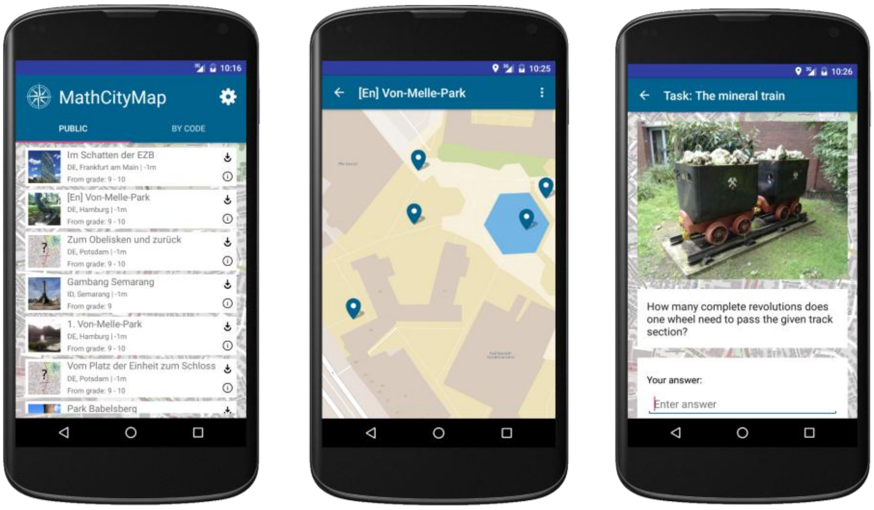


Figure 1: Screenshots of the MCM App

To describe the pedagogical functionality of MCM, we use the model by Drijvers, Boon and Van Reeuwijk (2010). It divides digital technologies into three groups of didactical functionalities: (a) do mathematics, (b) practice skills, (c) develop concepts. MCM offers mathematical tasks at real life objects where the user mainly can practice his skills.

GAMIFYING THE MATHCITYMAP APP

Following Morschheuser et al. (2017), we have analysed the MCM project prior to implementing gamification.

Analysis of the MCM supported math trail activity

Secondary school students, who are familiar with using smartphones and apps, are the target group of our project. A math trail in school is usually used irregularly (e.g. day’s hike, project days). In our approach, students collaborate in groups of three (one is using the MCM app, one is responsible for measuring and the last one is responsible for taking notes) and walk the math trail independently during math classes.

The math trail activity is divided into sub activities that are titled “working on a task”. Each sub activity consists of the following sequence: (1) finding the task’s location; (2) reading the task description; (3) collecting data; (4) transform task into mathematic model; (5) calculating the answer; (6) entering answer into the app and getting feedback; (7) optionally, taking hints and retry. During step (1), (2), (6) and (7) students use the MCM app.

Gamification goals

The gamification goals are based on the negative observations that were mentioned in the introduction of this article.

(1). Prevent students from guessing answers

(2). Increase intrinsic motivation for working on math trail tasks (decrease time that passes when walking from one task to the next).

Implementation

To prevent guessing we have decided to implement (1) points that the user is rewarded when answering a task correctly. When the user guesses too often, the maximum amount of possible points decreases. The second gamification is the (2) local leaderboard, which is based on the points gamification. The difference between a global and local leaderboard is that the first displays all users so that it is possible to see one's absolute ranking. The latter displays only the user's rank in comparison to the user in front and the user behind him. Additionally, we have added a computer player who is always the last.

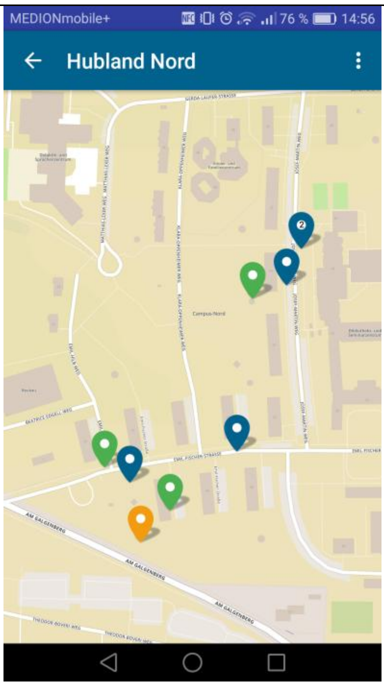
0: No gamification	1: Points	2: Local leaderboard
		

Table 1: Types of gamification in MathCityMap.

Research Question

Is there a difference in student's intrinsic motivation while walking a math trail using the MCM app with points or with leaderboard gamification?

METHODOLOGY

In December 2016, we conducted a pilot study with two ninth grade school classes (n = 47) comparing the intrinsic motivation between points (g1) and leaderboard (g2) gamification.

Study design

In the first 15 minutes, the participants learned how to walk a math trail with MCM. The functionalities of the app and the rules were explained. Subsequently, they had 90 minutes to work on the tasks independently in groups of three. The tasks were mainly about cylinders. Finally, they were asked to fill in a translated version of the Intrinsic Motivation Inventory (IMI, 1994) questionnaire. In this case, both groups were experimental groups. The first group walked the math trail with points gamification (g1), whereas the second group used the leaderboard gamification (g2).

Questionnaire

The used IMI questionnaire consisted of twenty-two 7-point Likert scale items that can be assigned to four sub scales. The sub scales represent positive or negative indicators for intrinsic motivation (see table 2). The students had to indicate how true the statements were for them (not at all true – very true).

Sub scale	**Example item**
Interest / Enjoyment (positive)	This activity was fun to do.
Perceived Competence (positive)	I am satisfied with my performance at this task.
Perceived Choice (positive)	I believe I had some choice about doing this activity.
Pressure/Tension (negative)	I felt pressured while doing these.

Table 2: Sub scales and example items (IMI, 1994).

RESULTS

An independent-samples t-test was conducted to compare intrinsic motivation for walking a math trail using the MCM app with points gamification (g1) and leaderboard gamification (g2). There was no significant difference in the scores of any sub scale:

Interest / Enjoyment: g1 (M=3.6, SD=1.4) and g2 (M=3.8, SD=1.1); t (45) = -.542, p = .59.
Perceived Competence: g1 (M=3.7, SD=1.5) and g2 (M=3.5, SD=1.5); t (45) = .352, p = .72.
Perceived Choice: g1 (M=3.8, SD=1.6) and g2 (M=4.2, SD=1.2); t (45) = -.815, p = .42.
Pressure / Tension: g1 (M=2.8, SD=1.3) and g2 (M=3.2, SD=1.4); t (45) = -.789, p = .43.

At the first glance, these results suggest that the two types of gamification do not differ in how they impact intrinsic motivation. However, when taking the sex of the participants into account the results of the sub scale Interest / Enjoyment do change.

	Gamification	Sex	M	SD	N
Interest /Enjoyment	Points	male	3,4290	1,34171	10
		female	3,7031	1,49078	13
	Leaderboard	male	4,1869	,96772	13
		female	3,2991	,99534	11

Table 3: Statistics of gamification and sex as independent variables

A two-way analysis of variance was conducted on the influence of two independent variables (gamification, sex) on the Interest / Enjoyment sub scale. The interaction effect was not significant, F(1,43) = 2.63, p = .112.

Finally, two independent-samples t-tests were conducted to compare the Interest / Enjoyment sub scale with the combination of gamification type and sex. The first test compared female participants with points gamification (M=3.7, SD=1.5) and male participants with points gamification (M=3.4, SD=1.3). No significant difference in score of the sub scale could be found, t(21) = -.456, p = .653. The second test compared female participants with leaderboard gamification (M=3.3, SD=1.0) and male participants with leaderboard gamification (M=4.2, SD=.97). There was a significant difference in the interest sub scale score, $t(22) = 2.2$, $p = .04$. These results suggest that the impact of points gamification (g1) on intrinsic motivation does not differ for ninth grade female and male students. Whereas the leaderboard gamification (g2) impacts the intrinsic motivation different depending on the sex of the participant.

DISCUSSION

In the conducted pilot study, no significant difference in intrinsic motivation between points and leaderboard gamification was found. However, the results indicate that points gamification influences the interest / enjoyment sub scale of male and female students equally (cf. Attali & Arieli-Attali, 2014) since no significant difference in their scores could be found. Whereas leaderboard gamification leads to a significant higher interest / enjoyment sub scale score for male students (M=4.2) compared to female students (M=3.3).

Mathematic classroom rates (at least in Germany) as a male domain (Budde, 2009). The results suggest that different gamification types might influence this issue in a positive or in a negative way. Prior to implementing gamification in math classroom, it should be considered carefully that it might favour one group and discriminate the other.

Prospects

The main study with 25 ninth-grade classes will be conducted in May / June 2017. The classes will participate in a pre-test and be divided into three groups: (g0) control group; (g1) points gamification; (g2) leaderboard gamification. Additionally, to the impact on intrinsic motivation, the evaluation of the gamification goals will be examined.

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