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At the Goethe University Frankfurt am Main a study amongst 9th graders was conducted. It was about the effects of a mobile app supported mathematics trail on the performance concerning tasks on cylinders. It was supported by the MathCityMap app. In the first test after the treatment, the treatment group performed significantly better than the control group. After half a year, the same test was written as a follow-up. Now the treatment group has nearly the same results than the first time, but the control group performed significantly worse. This leads to the assumption, that the treatment may have an influence on the long-term memory. This is supported by theories such as outdoor education, integrated thematic instruction, enactive learning or self-determination.

Keywords: Mathematics activity, handheld devices, mathematics trail, outdoor education.

Introduction

A mathematics trail (or maths trail) is a walk at which mathematical problems can be discovered and/or solved along the way (Shoaf, Pollak, & Schneider, 2004). To find these problems, a maths trail guide is needed, whether as a person or a printed/electronic version. Mathematics trails have been around at least since the early eighties (Lumb, 1980). The first publications mentioned the importance to make the mathematics in the environment visible for children (Blair, Dimbleby, Loughran, Taylor, & Vallance, 1983). Therefore, mathematics trails have been introduced internationally on the IMU conference on the popularisation of Mathematics (Blane, 1989). Although maths trails have been in use for quite some time now, surprisingly few studies have been conducted about them. So far, there has been no systematic approach to research the learning outcome and the long-term effects of mathematics trails in school.

Another way to use maths trails in school can be found by Toliver (1993), who let the pupils find mathematical tasks in the surrounding of the school. The focus is not to solve problems but to find some and therefore discover the mathematics around us. It took quite some time, since Traylor (2005) asked if maths trails have the potential to not only make mathematics visible but also improve the learning outcome of the pupils. She left this question without an answer but could show that a general treatment in problem posing does not increase the problem-solving skills of pupils.

Various authors have been stating the positive motivational aspects of maths trails (Shoaf et al., 2004), and newer quantitative studies have revealed this positive effect (Cahyono & Ludwig, 2017). Since we know about the influence of motivation towards performance in mathematics (Chiu & Xihua, 2008), there seems to be a clue, that running a maths trail is not only affecting the motivation but could also help to increase the performance of the pupils. On the one hand, Ryan and Deci (2000) have written on the three needs of motivation: autonomy, competence, and relatedness.

Sending pupils in small autonomous groups on a maths trail can support these needs. For sure the autonomy is given, but also the relatedness if the pupils work together.

On the other hand, maths trails are strongly supported by learning theories of Bruner (1971). Bruner stated that it is important for learning that it is represented on three levels, the symbolic, the iconic and the enactive level. Going on a maths trail directs to the enactive level, while the school lessons normally address strongly the symbolic level and illustrations on the blackboard and in textbooks supports the iconic level. If pupils go out and measure, they can see the real objects and discuss to choose the right model for the task. In addition to the iconic and symbolic level they have experienced in the classroom, they can get their hands-on mathematics in an enactive way. Running a maths trail is one way to enrich the school lesson by an enactive element. This idea of learning with all senses is also supported by the integrated thematic instruction model (Kovalik & Olsen, 1994). Kovalik and Olsen stated that learning with all senses, making real experiences instead of just reading of them, will be remembered longer by the children than any other form of lesson.

Furthermore, we know that outdoor education can have positive effects if it is carefully planned and conducted as well as being integrated into the school curriculum (Dillon et al., 2006). This should not be underestimated and taken care of when setting up a mathematics trail. And finally, yet importantly, walking a maths trail is a moderate physical activity, which we have clue for its positive effect on mental performance (Westman, Olsson, Gärling, & Friman, 2017).

MathCityMap

In addition to these approaches, the MathCityMap project was established at the Goethe University of Frankfurt (Jesberg & Ludwig, 2012). It provides users with a web portal as a GUI for a database of maths trail tasks and routes as well as with an application for smartphones (iOS and Android) to compile this data into a mobile trail guide (see figure 1). The app gives feedback on solutions (wrong/right) and the users can take hints from the app. Following the ideas of Aebli (1983) it is important to give direct feedback, so no wrong solution is without comment.

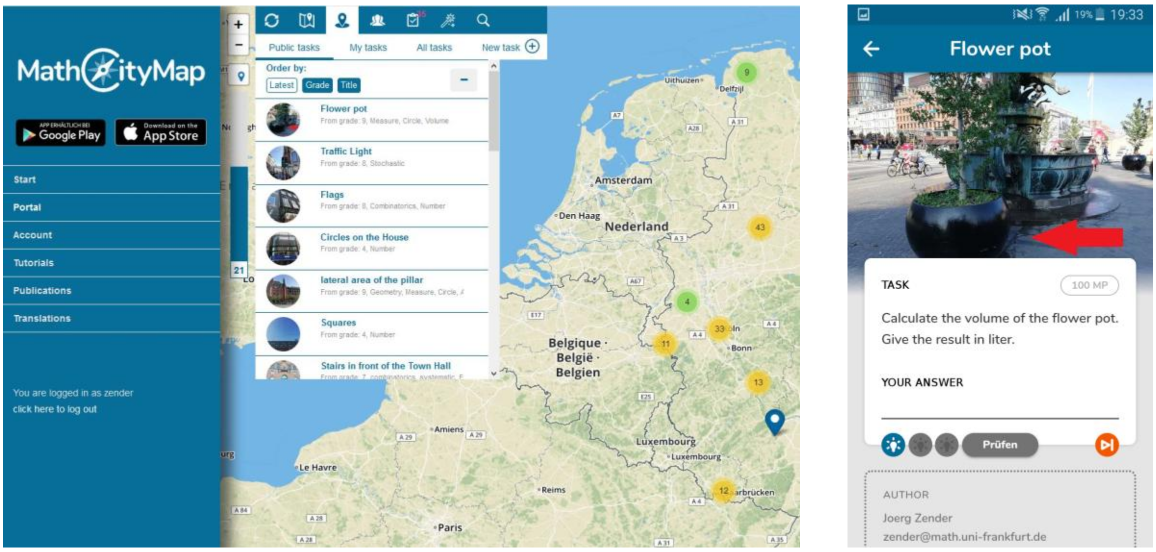


Figure 1: MathCityMap webportal (left) and smartphone application (right)

Research question

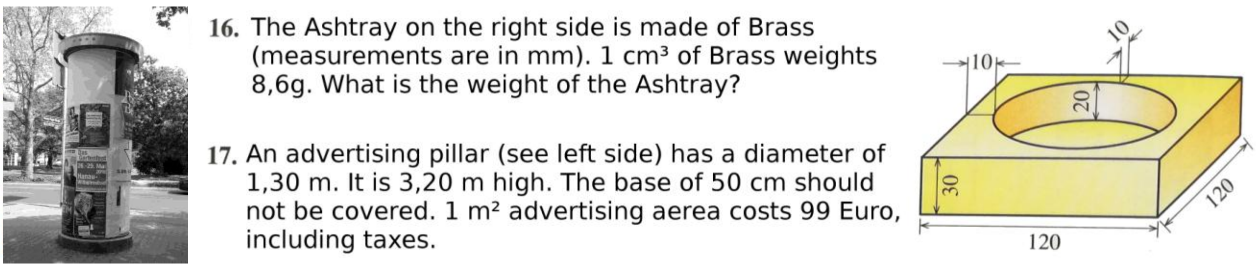
With all these clues, the question remains, what effects can we expect for pupils going on a math trail? Especially what effect does it have on the long-term memory? To answer these questions, we have conducted a study in 2017 in Frankfurt.

Method

In 2017, we collected 23 classes in the area of Frankfurt am Main and surrounding with a total of 629 pupils from 9th grade to conduct a study concerning the effects of mobile-supported mathematics trails with the MathCityMap app. All these classes wrote an entrance exam based on the German VERA8 test to measure the general mathematical performance of the pupils. Since some pupils missed the day of the exam, only 578 have participated. After this was done, the classes were separated in treatment and control group, to control the variable of mathematical performance. Also, from every participating school, at least one class was picked for control and one for treatment group, to control the variable of being on a certain school. Other variables that could influence the results, like the quality of the teacher, have been randomized by the number of pupils participating. A total of 323 pupils have taken part in the treatment. Both groups wrote another exam to compare their performance, only 529 participated in that exam. In the end, there were 273 pupils of the treatment and 182 of the control group we have full data from. For the follow-up test half a year after the treatment, we have full data for only 42 pupils from the treatment and 37 from the control group.

The treatment itself contained walking two maths trails for 90 minutes each in a group of three. The trails include ten tasks from which five (every second) was a task related to the topic of cylinders. After an analysis for German textbooks for ninth graders (see figure 2), we found only four different type of textbook word problems for cylinders of a certain amount (see table 1). Asking for

- the volume (V),
- the surface (S),
- the lateral surface (L) or
- the height (h), if volume and diameter or radius (r) is given.



16. The Ashtray on the right side is made of Brass (measurements are in mm). 1 cm³ of Brass weights 8,6g. What is the weight of the Ashtray?

17. An advertising pillar (see left side) has a diameter of 1,30 m. It is 3,20 m high. The base of 50 cm should not be covered. 1 m² advertising aerea costs 99 Euro, including taxes.

Figure 2: Part of a German textbook page with tasks on cylinders

Table 1: Analysis of German textbooks

Given	Asked	Book 1	Book 2	Book 3	Book 4	Book 5	Book 6	Total	In %
r, h	V	13	7	9	2	15	11	57	50,9
r, h	S	1	3	3	2	5		14	12,5
r, h	L	5	3	2	2	4	1	17	15,2
V, r	h	6		3		5	3	17	15,2
V, h	r	2	1	1				4	3,6
S, r	h					2		2	1,8
S, h	r							0	0,0
L, r	h							0	0,0
L, h	r	1						1	0,9
L, S	r							0	0,0
L, S	h							0	0,0
L, S	V							0	0,0
Total		28	14	18	6	31	15	112	100

For all these four kinds of tasks, an outdoor task has been created in both trails (see figure 3). In case of the advertising pillar (see figure 2), a real advertising pillar was used. Being outdoors, we tried to create authentic tasks in the sense of Vos (2011). The pupils used the MathCityMap app on smartphones provides by the Goethe University. On these phones, all progress has been logged, so that we have full data of the tasks solved by the pupils, the results they have given, the feedback they received, the time they needed and so on.

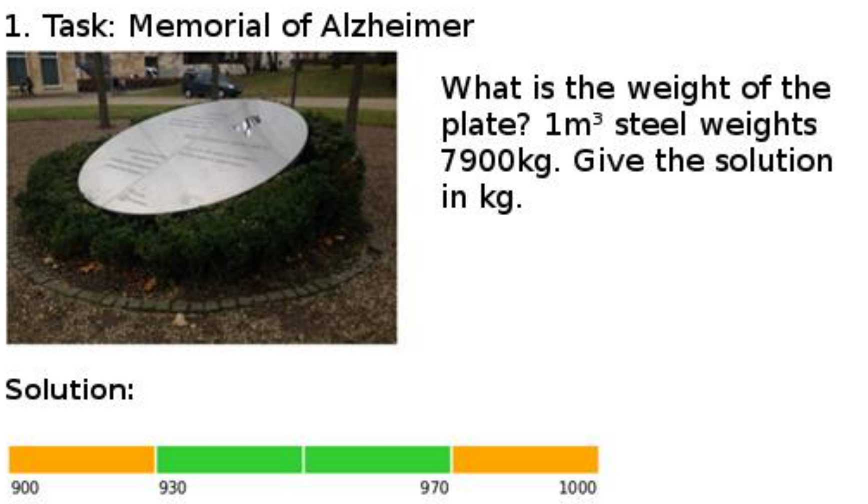


Figure 3: Sample tasks from the study about the weight of a cylindric plate

Results

For the first test after the treatment, the treatment group has performed significantly better than the control group (t-test, $p < 0.01$), but the effect size was small ($d = 0.398$). Divided into grammar school and secondary school, the effect was limited to the grammar schools (Zender & Ludwig, 2018). By dividing the grammar school pupils ($N = 256$) into three performance groups of the same size due to the results of the entrance exam, it was revealed that the low performer and the middle group had both shown significant differences between the treatment and the control group ($p < 0.01$ for both) with middle effects (low performer: $d = 0.631$, middle performer: $d = 0.699$). Only for the high performer, no effect could be found.

The Follow-Up test also shows some interesting results. Unfortunately, only two schools with two classes each have participated ($N = 79$). Both are secondary schools. Compared to the first test, the treatment group scored nearly with the same mean and there is no significant difference between the first test and follow up. On the other hand, the control group has had a significant difference, they got worse in the follow up (see table 2).

Table 2: Differences between the first test and the follow up test

Group	*N*	*M*	*SD*	*P*	*D*
Control	37	-1.838	1.860	0.000	-1.150
Treatment	42	0.071	1.538	0.384	0.034

Can the effect of the single maths trail tasks be estimated? The pupils have used smartphones from the Goethe University and their efforts have been logged on these phones. Therefore, we know precisely which tasks the pupils have solved, so that we can observe the learning outcome of different groups on specific tasks. One example is the type of task where the volume and the radius or diameter is given, and the height is asked. This was a task in the test after the treatment. We have the control group ($N = 196$) with no specific treatment and treatment group can be divided into three groups. Those who have not solved a corresponding maths trail task ($N = 118$), those who have solved one corresponding task ($N = 122$) and finally those who have solved both corresponding tasks ($N = 73$). The difference between having at least one task solved to none task solved is significant (X^2, $p < 0.01$) with a small effect ($V = 0.19$), see table 3.

Table 3: Effects on solving maths trail tasks to solving textbook task

		Related tasks in the Treatment		
	Control	*None solved*	*One solved*	*Both solved*
Textbook solved	10%	7%	23%	33%
Textbook not solved	90%	93%	77%	67%

About the benefit of using mobile technology to support the math trail, we also have data. As mentioned, the smartphones logged the progress of the pupils. From the existing log data, we know that 78% of the groups, who tried to solve a task, were successful. Only 37% of them were successful in the first try. This leads to the assumption that in a setting without technology, 63% of the groups would have written down wrong answers and would have been aware of their fault only later in the classroom.

Discussion

In his study in Indonesia, Cahyono (2017) could show the significant but small effect on the mathematical performance of pupils when taken part in a maths trail. These findings are similar to the one we have in Germany, also a significant and mostly small effect on the short run. What is new is the follow-up test, which gives us the hint that the results of the test are stable for the treatment group and getting significantly worse for the control group. Although the sample size is small, and we must be careful with clues, the results are supported by the theories of Bruner (1971) and Kovalik and Olsen (1994) according to the importance of enactive learning. It is also interesting that the treatment group we have tested in the follow-up did not perform significantly better in the first test, but their adopted knowledge seems to be more stable than that of the control group.

One possible assumption is that the mobile supported maths trails (which can be created and conducted with MathCityMap) have the potential to influence the mathematical performance of pupils not only for the moment of the treatment but also for the long-term memory. The technology is in two ways important for the maths trail activity. First, the teacher can use the technology to create a trail, monitor the pupils while being outside and collect their results. So, the teacher can open up the classroom to go outside but is still in control of the learning environment without being physically present around the pupils.

On the other hand, we have also benefits for the pupils. As mentioned above, they get direct feedback on their solutions. For sure, they validate their results amongst each other in the group of three, but the app allows getting a validation from the teacher, while the pupils are still at the object of the task. The feedback in combination of the available hints makes it possible that they can revise their solution, get new measurements, find another model and so on. With the support of the log data of the smartphones, it could be shown, that only about 37% of the pupils are able to solve a task properly on the first try. 63% of the pupils would have noticed their fault later in the classroom. Too late to revise the task and perhaps not being interested to solve it anymore. By the high number of right solutions after feedback, we can estimate the motivational potential the app has for the pupils. The use of technology is the main reason the pupils finish the task properly. The app is the main reason that a successful maths trail could be set up by the teacher without accompanying the pupils. This leads to the possibility to be on the maths trail as an autonomous group of three for the pupils. From Deci and Ryan (2000) we know about the importance of autonomy for intrinsic motivation, and Hattie (2014) could show the positive effects of working in small groups. These positive effects are results of the maths trail, but the technology allows the teacher to set up such a powerful learning environment.

Further research is needed to give better clue if this assumption holds true. Moreover, if it does hold true, we have to research deeper on the reasons for success. This is very important, not only to give the advice that maths trails are good for schools but also to point out what it is to take care about when running a trail at school to make it a success. What we do know so far is that going out on a maths trail should be done more frequently. A single event is not half as strong as two related events (Zender & Ludwig, 2018).

What we also now have a clue about is that the maths trail tasks have an influence on the learning outcome. It is not "just" movement and fresh air since we can see that the performance of the control group and the group without solving corresponding tasks are very similar. Because the treatment group had some of their lessons replaced by the maths trail activity, it could explain, why they are a bit worse, if they have not solved a corresponding task. There is maybe a lack of practice, and this is something a teacher should care about when designing a maths trail activity. On the other hand, we can see the significant increase of success on the test task when solving one or even both corresponding tasks of the maths trail. So, we know now that there is an effect, but little do we know about criteria of good tasks. What makes a maths trail task successful? Also, on this interesting topic, further research is needed.

At last, we have clues about the benefits of using technology, the direct feedback for example. We can conclude from the data that most of the pupils would have written down wrong answers without the technology. But we have no control group walking a maths trail only pen and paper to determine the effect size on the learning outcome. Again, further is research is needed. We are just at the beginning to understand maths trails and technology.

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