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Effective or not? The impact of mobile learning on students' interest, self-efficacy, and performance in outdoor mathematics education

Simon Barlovits and Matthias Ludwig

Goethe University, Institute for Education of Mathematics and Computer Science, Frankfurt, Germany; barlovits@math.uni-frankfurt.de

Interest and self-efficacy are seen as important requirements for students' performance. Two approaches that can promote students' affective attitudes towards mathematics are mobile learning as well as outdoor learning. The latter one can be realised in mathematics education by so-called math trails, which connect math tasks to real outdoor objects. Math trails can be enriched by mobile applications, such as the MathCityMap app. In a quantitative study (N = 257), we compare math trails with or without digital support regarding students' interest, self-efficacy, and performance. The results show that the use of the mobile app has no influence on students' interest and self-efficacy. Nevertheless, it is beneficial since it leads to a significant increase in the number of tasks solved, while the number of tasks processed is comparable. As the analysis of the app usage shows, this result can be attributed to the valuable support of the app in form of hints and immediate answer validation.

Keywords: MathCityMap, student interests, mobile learning, outdoor education, performance.

Introduction

“While relatively new in the digital landscape, mobile technologies and apps offer fresh opportunities to re-envisage some aspects of the mathematics learning experience and enhance students' engagement and mathematical thinking” (Larkin & Calder, 2016, p. 1). As stated by Larkin and Calder (2016), the use of mobile technologies is associated with the expectation to support students' learning process at both affective and cognitive levels. For the cognitive level, meta-studies such as Sung et al. (2016) report a positive impact of the use of mobile applications on student's learning progress.

The affective level is generally considered as an important prerequisite for students' learning progress (Schukajlow et al., 2023). Outdoor learning tends to positively influence students' affections towards the environment and the subject (Ayotte-Beaudet et al., 2017). Therefore, shifting the location from the classroom to the outdoors seems to be desirable in terms of students' affections. This shift can be supported by the use of mobile technologies (Larkin & Calder, 2016).

This study aims to present an approach to support outdoor mathematics learning with technology. In doing so, we draw on the so-called math trail idea and complement it with a mobile learning approach. Two learning scenarios, i.e., math trails with and without mobile technology, are contrasted with regard to their effect on a cognitive and affective level.

Theoretical Framework

Mobile Learning

Mobile learning can be understood as “learning across multiple contexts, through social and content interactions, using personal electronic devices” (Crompton, 2013, p. 5). This perspective does not

only focus on the portability of mobile devices but emphasises that the educational process can be enriched by mobile devices regardless of the context: mobile learning can take place in formal and informal settings and especially inside and outside the classroom (Crompton, 2013). Regarding mathematics education, the potential of mobile learning for providing visual and dynamic representations, enhancing collaborative work processes, and facilitating transfer between different learning situations – for indoor and outdoor mathematics – is emphasised (Larkin & Calder, 2016).

Mobile Math Trails

One approach to outdoor mathematics education is the math trail method. A math trail can be described as a walk to discover and experience mathematics in one’s own environment (Shoaf et al., 2004). By working on tasks about interesting objects, students gain first-hand experience by applying their knowledge in practical situations. They work together in teams, discuss and communicate mathematical ideas and collect the necessary data by counting, measuring or estimating (Cross, 1997).

In recent years, the math trail idea has been enriched by mobile learning approaches, e.g., by using the MathCityMap app (Ludwig & Jesberg, 2015). It offers GPS navigation to guide students to the location of the tasks and displays the task formulation. On demand, students can access up to three *hints*. An *immediate answer validation* provides feedback on the correctness of the entered solution, allowing students to revise the task after an incorrect entry. In addition, a *sample solution* is provided, which shows one possible way of solving the task (Ludwig & Jesberg, 2015). An exemplary task process by using the MathCityMap app is shown in Figure 1.

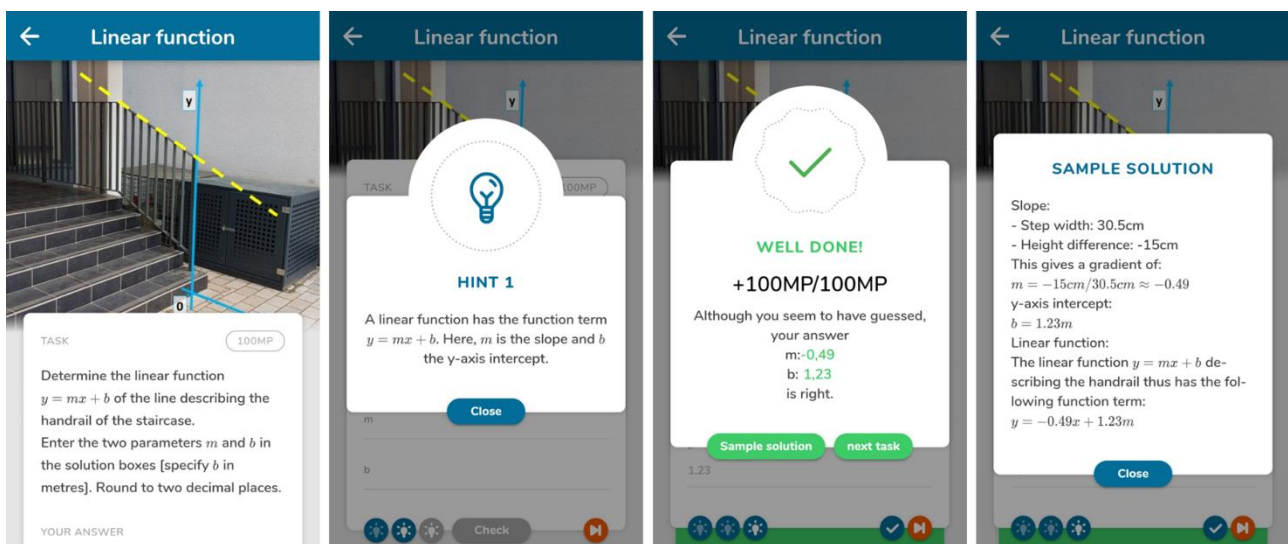


Figure 1: The math trail task “Linear function” displayed in the MathCityMap app, including task formulation, hints, answer validation and sample solution (from left to right)

State of the Art

According to the meta-study by Sung et al. (2016), mobile learning can generally be seen as beneficial for students’ learning with a medium effect size (Hedges’ $g = .523$). Also, the use of mobile devices in mathematics classes or in outdoor learning environments can be considered effective for students’ learning with a small effect ($g = .338$) and a medium effect ($g = .760$), respectively. It can therefore be assumed that mobile outdoor education has a positive effect on students’ mathematics learning.

In recent studies on mobile maths trails, Buchholtz (2021) as well as Ludwig and Jablonski (2021) highlighted the potential of maths trails to promote modelling skills. In terms of students' learning progress, Zender et al. (2020) carried out quantitative studies in Germany and Indonesia. They reported a slightly positive impact on students' performance after running math trails compared to a control group. On the affective level, students were highly motivated to work on the mobile math trails, both in terms of the high motivation scores achieved and, for Indonesia, compared to a control group with regular mathematics instruction (Cahyono & Ludwig, 2017; Zender et al., 2020).

Research Questions

Even though these results underline the value of mobile math trails for mathematics education, the impact of mobile learning remains unclear. In studies in Indonesia and Germany, the students always worked on mobile math trails. In other words: "Both studies did not try to run a maths trail without technology to compare that to a mobile app supported maths trail" (Zender et al., 2020, p. 10).

The present study aims to fill this research gap. In order to specify the benefits of mobile applications for math trails, we compare students' work on non-digital and mobile math trails at the affective and cognitive levels. In other words, we compare the work of the 'classic' paper-and-pencil math trails with mobile math trails to quantify the added value of app usage on students' experience and performance. The paper addresses three research questions:

- *RQ1*: What is the impact of mobile apps on students' *affective attitudes* on math trails?
- *RQ2*: What is the impact of mobile apps on students' *performance* on math trail tasks?
- *RQ3*: In case *RQ1* or *RQ2* show an impact, what *app features* are responsible?

Operationalisation

RQ1: On the affective side, this study focuses on students' interest and self-efficacy, as these can be seen as important prerequisites for the cognitive outcome (Grigg et al., 2018; Schukajlow et al., 2023).

RQ2: On the cognitive level, students' performance is operationalised as the ability to solve tasks of a math trail. Thus, the work process is analysed in terms of the solution rate.

RQ3: In order to analyse students' use of the MathCityMap app, we focus on the app features hints, the answer validation and of the sample solutions. Since it can be assumed that these features are used more regularly when the task is perceived as difficult, a task with a lower solution rate is selected for the analysis. This specific task is shown in Figure 1.

Method

To answer the research questions, a quasi-experimental study in a pre-post-test design was conducted with a total of 13 classes in the school year 2021/2022. In this study, 7 classes worked on math trails supported by mobile technology, more specifically by the MathCityMap app (MCM group; N = 133). The other 6 classes had no digital support and thus no access to app features such as hints, answer validation, or sample solutions. They worked on the same math trails with the same task that was presented on a sheet of paper instead of in the app (P&P group; N = 124).

The classes from German high schools (8th grade, approx. 14 years old) were randomly assigned to one of the two groups. Both groups ran math trails on linear functions twice (for 90 minutes each).

Here, the students worked in teams of three. To check for equal baseline conditions, a pre-test was conducted including (a) a questionnaire on students' interest and self-efficacy experience in mathematics and (b) a test on their achievement in linear functions. In a post-test after the treatment, a questionnaire on their interest and self-efficacy experience in running math trails was administered.

All constructs of the questionnaires consist of four related items, e.g. "I like mathematics"/"I like working on math trails" (interest) and "I have talent for mathematics"/"I have talent for math trails" (self-efficacy). The tested items are adapted from Rakoczy et al. (2005) and are given on a 4-point Likert scale. Cronbach's α is calculated for all related items each. Since they show a high internal consistency, a sum score is computed per scale, resulting in a range from 0 to 12. The data analysis is carried out with *JASP* by using *Welch t-tests*, *Wilcoxon tests* and *chi-squared tests* ($\alpha = .05$ each).

To answer *RQ2*, the calculated solutions of the student teams in both groups are rated dichotomously in terms of correctness (solving or failing the task). Results are compared for both groups using *Welch t-tests*. Here, we focus on the twelve tasks of the first math trail. For *RQ3*, the event-log of the MathCityMap app is evaluated to determine how often the named app features are used by the student teams. In doing so, we focus on one specific task shown in Figure 1.

Results

Baseline Conditions

The baseline conditions between the MCM and P&P group regarding interest and self-efficacy in mathematics as well as achievement in linear functions were controlled in advance.

- Interest in mathematics: $t(240.60) = -1.15, p = .252$
- Self-efficacy in mathematics: $t(238.89) = -1.12, p = .265$
- Achievement in linear functions: $t(246.95) = 0.27, p = .785$

Since no differences could be found between the groups, it can be assumed that both groups are comparable regarding the tested concepts.

Interest & Experience of Self-Efficacy

Interest and self-efficacy experience in math trails are shown in Figure 2 for the MCM and P&P groups. Both groups appear to have a high interest in math trails, as the median of 8 for both groups is clearly above the theoretical median of 6. The MCM group has a more compact distribution than the P&P group (Figure 2, left). Regarding self-efficacy (Figure 2, right), a similar distribution of both groups can be observed, each with a median of 7.

The interest and self-efficacy experience scales of the two groups are compared using *Welch t-tests*.

- Interest in math trails: $t(220.98) = 1.52, p = .129$
- Self-efficacy in math trails: $t(232.51) = -0.97, p = .331$

The statistical analysis confirms the boxplot analysis: no significant differences can be found between the two groups in terms of interest and self-efficacy experience in running math trails.

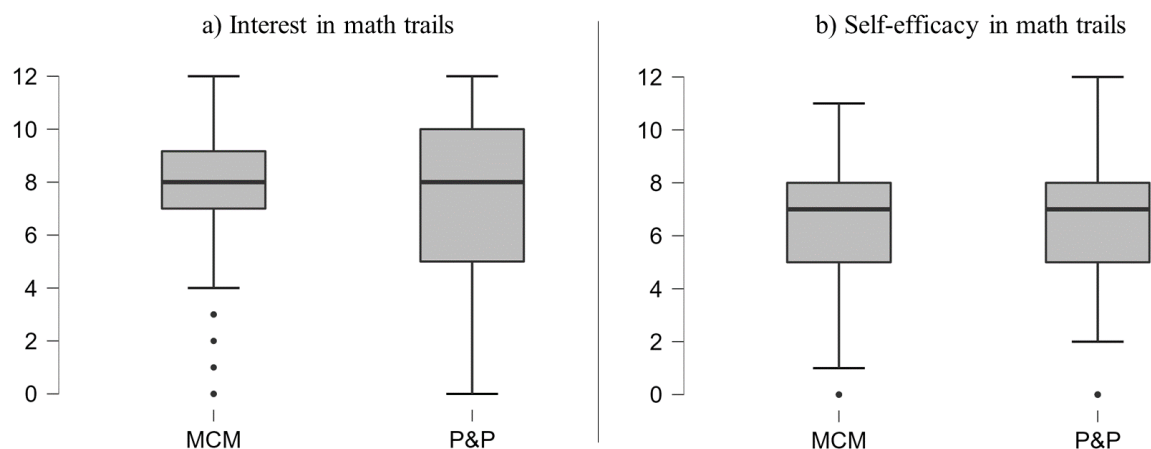


Figure 2: Boxplot of interest (left) and experience of self-efficacy in math trails (right) for both groups

Next, we check whether the interest and self-efficacy experience is higher than the scales' theoretical median of 6. Based on the previous analyses, the groups can be considered comparable and thus are treated as one sample here. Since the normality assumption is violated, *Wilcoxon tests* are performed.

- Interest in math trails: $W = 22255.0$, $p < .001$, $r = .619$
- Self-efficacy in math trails: $W = 15836.5$, $p < .001$, $r = .291$

A significant difference from the theoretical mean was found for both scales with a strong effect for interest in math trails and a small effect for self-efficacy experience.

Intermediate result 1: Both groups showed a high level of interest and self-efficacy experiences. However, since no differences were found between the groups, we assume this result was caused by the outdoor setting. The use of the mobile app did neither lead to an increase in interest and self-efficacy, nor did it lead to a decrease.

Performance

For students' performance in the outdoor activity, we take a closer look at the first math trail. Figure 3 shows the number of processed, solved and failed tasks per group. Here, the number of processed tasks is understood as the sum of solved and failed tasks. A task is classified as "solved" if the solution calculated by the student team is within the solution interval expected by the researchers. Otherwise, the task is rated as "failed" (i.e., not solved). In total, work processes of 52 student teams of the MCM group and 46 student teams of the P&P group are included in the analysis.

Teams in both groups appear to process a comparable number of tasks, as the median of the MCM group is 8.5 and that of the P&P group is 9 (Figure 3, left). However, the number of tasks solved seems to be noticeably higher in the MCM group than in the P&P group (Figure 3, middle). In addition, the MCM group tends to fail less tasks than the P&P group (Figure 3, left).

To verify this boxplot analysis, the two groups are compared in terms of the number of tasks processed, solved, and failed using *Welch t-tests*.

- Number of processed tasks: $t(95.74) = -1.17$, $p = .246$
- Number of solved tasks: $t(94.56) = 4.14$, $p < .001$, $d = .831$
- Number of failed tasks: $t(93.07) = -7.89$, $p < .001$, $d = -1.60$

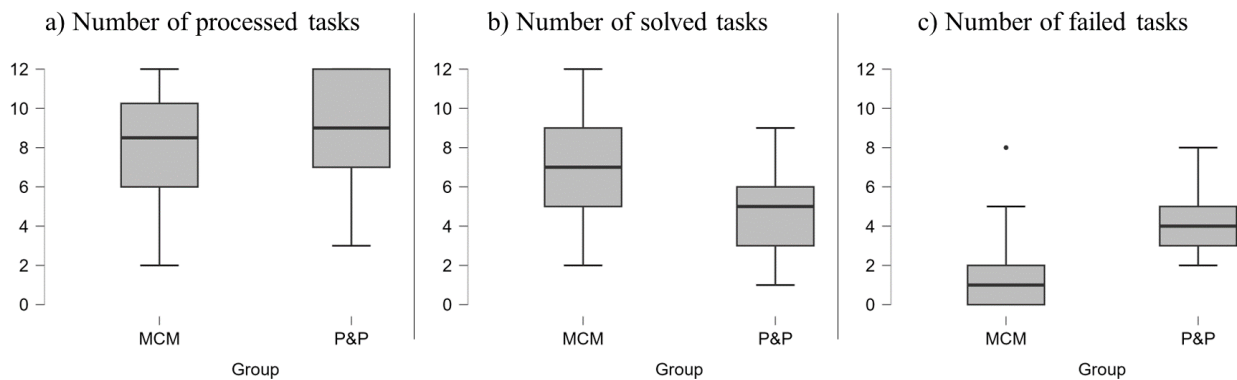


Figure 3: Boxplot of processed, solved and failed tasks for both groups (from left to right)

Again, the statistical analysis confirmed the interpretation of the boxplot: Firstly, no significant differences could be found in the number of tasks processed. However, secondly, the number of tasks solved was significantly higher and the number of tasks failed was significantly lower for the MCM group compared with the P&P group (strong effect each).

Intermediate result 2: Although students of both groups had similar baseline conditions and showed the same interest and self-efficacy in running math trails, the MCM group supported by a mobile app showed a significantly better performance than the P&P group that did not receive digital support.

Usage of App Features

Finally, it is investigated why the MCM group was more successful in solving math trail tasks than the P&P group. Therefore, we examine students' work processes for the task "Linear function" (see Figure 1) and a similar task also part of the first math trail. The tasks were solved in 37 out of 67 task processes by the MCM group but only in 18 out of 69 processes by the P&P group, $X^2(1) = 11.98$, $p < .001$, $\phi = .297$ (small to medium effect). To explain the higher solution rate of the MCM group, the use of the app features hints, answer validation and sample solution is analysed in the following.

Hints were used in 45 out of 67 task processes, implying that the feature was used by a majority of student teams for this task. A *chi-squared test* shows that students of the MCM group who used the hints were significantly more likely to solve the tasks than those who did not (28 out of 45 and 9 out of 22, respectively), $X^2(1) = 9.31$, $p = .002$, $\phi = .201$ (small effect). Thus, within the MCM group, using the hints tends to be a factor of success for solving the task. Also, the *answer validation* seems to be an important feature: on average, each student team of the MCM group made 2.1 incorrect entries by processing the task type "Linear function". In this case, the student teams were informed by the app about the incorrect entry and thus had the opportunity to revise the task.

The importance of hints and answer validation can also be shown by comparing the task processes of student teams in the MCM group that used at least one of the features or used none (see Table 1). Using the app features led to a doubling of the solution rate, resulting in a small to medium effect in favour of student teams using the features, $X^2(1) = 2.19$, $p = .002$, $\phi = .270$. Moreover, the student teams in the MCM group that did not use the feedback functions only had a solution rate comparable to the P&P group, $X^2(1) = 0.18$, $p = .677$. The third feedback feature, i.e., the *sample solution*, was only called after a task process and is therefore not considered important for the particular task.

Table 1: Comparison of the solution rate taking into account the use of feedback features

Group	N	Task solved	Task failed	Solution rate
MCM Use of Hints or Validation	51	32	19	63 %
MCM No Use of Hints or Validation	16	5	11	31 %
P&P	69	18	51	26 %

Intermediate result 3: Based on the task analysis, hints and answer validation are seen as important features to support the work on math trail tasks. We assume that hints guide students through the task process, while the answer validation encourages them to check and revise their own calculations.

Discussion & Outlook

Interest and the experience of self-efficacy are considered important prerequisites for mathematical achievement (Grigg et al., 2018, Schukajlow et al., 2023). These attitudes can be fostered in mathematics education by both the use of mobile technologies (Larkin & Calder, 2016) as well as by moving the setting outdoors (Ayotte-Beaudet et al., 2017).

In this paper, a form of outdoor mathematics instruction – so-called math trails – was presented. Hereby, math trails with and without digital support by the MathCityMap app were compared. Consistent with Zender et al. (2020), we showed that running math trails achieves above-average levels of student interest. Additionally, our study showed that (a) running math trails leads to an above-average self-efficacy experience. Also, previous research was extended by the finding that enriching math trails by mobile technology has no impact on students' interest or self-efficacy efficacy compared to 'classic' and non-digital math trails.

In contrast, a significant difference was found in terms of students' performance in math trails with or without digital support: while a comparable number of tasks were processed by both groups, the use of technology resulted in a significant increase in the number of solved tasks, and a significant decrease in the number of failed tasks. Since both groups had comparable baseline conditions, this higher success in solving the outdoor math tasks can be clearly attributed to the use of the smartphone app. From the brief analysis on students' app use, we assume that this result can be explicitly linked to feedback through hints and answer validation given by the MathCityMap app.

From a more general perspective, the following two conclusions can be drawn regarding mobile learning and outdoor mathematics: The present study indicates that the high interest in the outdoor learning situation seems to outweigh the impact of mobile learning on students' interest. Nevertheless, the mobile learning support in outdoor activities, in this case by the MathCityMap app, is seen as beneficial as it tends to enhance students to be more successful in solving the given tasks.

However, a more detailed analysis of app feature usage is needed to examine *how* the student teams use the tool for getting support in outdoor settings. A first step in this direction was taken by Jablonski et al. (2023). In addition, we plan to investigate whether the higher performance of digitally supported teams also leads to higher learning success compared to teams that did not receive digital support.

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