Exploring mathematics outside the classroom with the help of GPS-enabled mobile phone application

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Abstract. The aim of the study is to explore the potential of the mobile app-supported math trail program in promoting students’ intrinsic motivation for the engagement in mathematics and the opportunities of mathematical outdoor activity in particular. Explorative design research was conducted on nine secondary schools in the city of Semarang, Indonesia, with 272 students and nine teachers. Data were gathered using participatory observation, interviews, questionnaires, and student worksheets. The findings indicate that students were highly intrinsically motivated to be involved in mathematics learning. They found it easy to engage in the activities and gain relevant mathematical experiences. Students indicated they learned to use advanced technology for outdoor activity and to do the mathematization. The study suggests that school and public can take advantage of the result of this study. Further research in other places is needed to exploit its potential and future development.

1. Introduction
Mathematics plays a role both in our daily and professional lives as individuals and members of society. People, therefore, need to be able to apply basic mathematics to their everyday lives, a skill that is termed as ‘mathematics literacy’ [1]. In the educational context, mathematics activities should provide the opportunity for students to experience the subject in a meaningful way that they can well understand [2]. Furthermore, students should be offered real-world situations that are relevant to their role as citizens or their areas of interest [3]. Taking mathematics outside the classroom allows students to experience it [4]. This can show them that mathematics is all around and not merely in their textbooks.

Recently, in some countries, there has been an increased interest in the development of outdoor and adventure education programmes [5]. Various activities outside the classroom have been specifically designed to increase student engagement. In mathematics, one of the outdoor educational programmes that have been elaborated is the math trail, namely, a path to discovering mathematics [6]. Although the math trail project is not new, supporting this outdoor education with mobile technology is an innovative approach to this outdoor educational programme. This most recent stage of the integration of this modern-day technology to the math trail is the basis for the development of the GPS-enabled mobile phone app–supported math trail program in this study.

This program began to be implemented in Indonesia from 2013, as tailored to the country’s situation. The implementation is motivated by the situation and problems in mathematics education in...
this country. Based on the result of the PISA 2012 study, 15-year-old Indonesian students were ranked 64th out of 65 countries, with a mathematics score of 375, and 75.7% of them unable to reach level 2 [7]. This means that Indonesian students cannot extract the relevant information of a given task or use basic algorithms to solve mathematics problems. An international survey also shows that only approximately 20% of Indonesian eighth-grade students like learning mathematics and only 3% are confident in their abilities in mathematics [8].

To address the issues mentioned above, this study aims to explore the potential of the program in promoting students’ intrinsic motivation for the engagement in mathematics and the opportunities of a mobile app-supported mathematical outdoor activity in particular.

2. Theoretical background
The theoretical framework for this study is underpinned by the concept of the math trail programme, the use of mobile technology to support it, and the motivation to engage in mathematics.

2.1 Math trails
A math trail is a planned path consisting of a series of stops where students can explore mathematics in the environment ([6], [9]). It was created as a medium for experiencing all characteristics of mathematics [6]: namely, communication, connections, reasoning, and problem-solving [10]. On the trail, walkers can simultaneously solve mathematical problems encountered along the path, make connections, communicate and discuss ideas with their teammates, and use their reasoning and skills in problem-solving [11].

Dudley Blane and his colleagues first developed the math trail by blazing trails in the center of Melbourne as a family holiday activity [12]. The programme was then strengthened when some schools took advantage of the trails by integrating them into their mathematics learning programmes [6]. The success of this idea allowed the programme to be adapted and applied in different places. Various cities such as Vancouver, Boston, Philadelphia, and San Francisco saw the emergence of several math trail projects [11]. Trail walkers follow the planned route and solve mathematical problems encountered with the assistance of a guide or map.

2.2 Mobile technology for math trail
With the recent rapid development of mobile technology [13], it is possible to collect tasks and design a math trail guide based on a digital map. These advantages have been exploited through this study, so that trail walker can access tasks and carry out the math trail with the help of GPS-enabled mobile devices ([14], [15]). This innovation has arisen in tandem with recent developments in mobile technology and mobile phone use, which have seen significant improvements [16], leading to the burgeoning of sophisticated mobile phone applications (apps), including those intended for use in outdoor activities. It is necessary to explore the potential of mobile technology for use in outdoors mathematics learning, and in so doing, to engage students, as trails walkers, in meaningful mathematical outdoor activities.

Using mobile technologies in learning activities is now common practice, and these technologies offer the advantages of learning opportunities. The learning process in which learners make use of these technologies is referred as ‘mobile learning’ [17]. One of its benefits is the opportunity to situate learning outside the classroom in the real world. Mobile devices have the potential to integrate the characteristics of effective learning, such as situated realistic learning, motivational power, and teamwork [18]. Mobile technologies thus facilitate engagement in a mixed reality environment [19].

2.3 Motivation in mathematics
Student engagement in learning processes as having a positive impact on their understanding of new knowledge and their flexibility in using the new information [20]. Engagement refers to the behavioral
intensity and emotional quality of involvement and is related to expressions of motivation [21], which can be defined as the ‘potential to direct behavior through the mechanism that controls emotion’ [22]. Motivation, as a potential, cannot be detected directly, but this could be identified if it expresses in cognition, emotion, and behavior [22].

Furthermore, motivation is famously distinguished between two poles: intrinsic and extrinsic motivation [23]. Five dimensions of learning orientation could also be characterized as having these two motivational poles, namely: choosing challenging tasks against easier work given; curiosity or interest in the tasks against receiving grades; independent against dependent mastery; independent against reliant judgment; and internal against external criteria for success [24]. Of the two poles, state that, psychologically, engaged learners are intrinsically motivated by curiosity, interest, and enjoyment, and are likely to want to achieve their own intellectual or personal goals [25].

2.4 Statement of research question
Having outlined the background and theoretical framework for this study, we can clarify the research question as: How can a math trail programme supported by the use of mobile phone application intrinsically motivate students to engage in meaningful mathematical activity?

3. Methods
To address the research questions, explorative design research was conducted. In this study, a mobile phone app-supported math trail program was designed. Then a small-scale field experiment was held with the small group of students and teachers, followed by large-scale field experiment with students at nine schools in the city of Semarang, Indonesia.

In all experiments, researchers observed the students’ activities during the activities and debriefed the students afterward. Notes were made, and the student's worksheet data were collected. Students completed a questionnaire immediately after the activity. Further, qualitative and quantitative methods were employed to analyze the data.

4. Results and discussion
By following the theory, the model of the GPS-enabled mobile phone app-supported math trail programme was designed to be implemented in Indonesia tailored to the local situations, conditions, and needs. The mobile phone app was also created in this study. It is a native app that displays the math trail routes/map, including the coordinates of the math trail tasks and the user’s current position, the authentic mathematical problems, the information about the tool needed in solving problems, the hints on demand (if needed by the users) and the feedback on the answers entered. The app also gives brief information related to the object, such as its history, its function, etc. Figure 1 shows some of the interfaces of the app.

In addition to making the app, 87 tasks, grouped into 13 math trail routes scattered among various areas in the city of Semarang, Indonesia, were also designed by educators (including teachers through training and a workshop). There were six to eight tasks for each trail with a variety of topics located in a safe and comfortable environment. The trails were designed in several school areas, city parks, historical buildings, markets, tourist attractions and other locations.

The math trails and the tasks were then uploaded into the portal so that users could access them through the mobile app. Trail walkers needed about two hours to explore a trail (about 1–2 km length) and to solve the problems encountered along the path. The math trails’ and mobile app’s designs passed the evaluation process, through validation by experts, and the simulation involved a small group of students and teachers that were considered eligible for use in the next step, namely the field experimental step.

Large-scale field experiments were conducted with 272 students and nine mathematics teachers. Each school was represented by a class consisting of an average of 30 students. They were divided into groups of five to six members. Four schools carried out activities outside the school while five
schools conducted activities in the school area. These choices were made because of conditions and situations (such as safety and availability of teaching and learning time) unique to each school (Figure 1).

Figure 1. App interfaces (Map: ©OpenStreetMap contributors)

The activities were conducted during normal school hours over two 45-minute periods beginning with the teachers giving a brief explanation of the learning activities and goals. Groups then began their journeys, each from a task location that was different from the others (Group I started at task I, Group II from task II, and so on). As the groups trekked the trail, teachers observed and supervised student activities but were not expected to assist because all the necessary information was to be provided by the app.

Once the activity was completed or maximum time allowed for the activity had passed, the students moved to the next task. After completing the trail, each group returned to class, then discussed with the teacher about the task solutions and what they learned along the trail. In general, the activities ran smoothly, the app worked well, and the rules and the goals of the programme proved to be comprehensible. Based on observations of the nine secondary schools, approximately 97% of students were actively engaged in the math trail activities from the beginning to the end, and almost all students enjoyed the activities.

To ascertain the motivation of the students while engaging in the activities, we reviewed the dimensions that can be characterized as having both an intrinsic and extrinsic motivation pole and the changes in the students' learning orientation. The students were asked to complete a questionnaire twice, namely, before running the activities and after gaining experience from their engagement in the activities.

Compared with the initial conditions, we see in the diagram that there was a change in the orientation of students' motivation from extrinsic to more intrinsic. The result of the Mann-Whitney U test showed that p values for all dimensions were .000 (less than .001). This indicates that the students' motivation in these two conditions was significantly different. The mean scores for before and after implementation were as follows: 3.74 versus 4.37 for Internal Criteria (p = .000); 3.64 versus 4.45 for Preference for Challenge (p = .000); 3.39 versus 4.39 for Curiosity/Interest (p = .000); 3.91 versus 4.44 for Independent Mastery (p = .000); and 3.39 versus 4.34 for Independent Judgment (p = .000). Students' criteria for success, therefore, moved from external criteria to becoming more internal.

The data show that there was an increase in the number of students who reported that they preferred working hard at the challenging tasks than the easy tasks. The more difficult the given task, the more challenging it was for the students to solve it. After implementation, most of the students worked on the tasks out of interest and curiosity—not merely because the teacher had assigned them to do the activities. The data also show that students enjoyed the activities, although they did not receive a grade for it. Students understood that they were not competing to get better grades than the other
groups: as there was no assessment, it was clear to them that this was not a competition. They knew that the goal of the activity was to learn mathematics, and not to test their skills.

Their motivation to engage in this activity led them to experience mathematics. By observing students’ work, interviewing them, and evaluating their work on the answer sheet, we analyzed how they worked at completing mathematics tasks in this activity. This has been undertaken with regard to the aspects or stages of mathematising [17] mentioned in the theoretical framework: starting with a reality-situated problem (in this study, we named it Stage I), organizing it (Stage II), transforming the real problem into a mathematical problem (Stage III), solving the problem (Stage IV), and realisation (Stage V).

Figure 2 The task about the volume of a cylinder-shaped pond at the Bubakan Roundabout

An example of student work on the problem of the Bubakan Roundabout task follows. As shown in Figure 2, the question in this task was: ‘How many bottles of water (1 bottle=1500 mL) are needed to fill the pond?’ To understand the mathematical activity of the students in this task, we observed a group as they were solving the problem, interviewed them, and analyzed their work. As seen in Figure 3, in the first stage, we knew that they understood the problem, which was to look for the volume of a cylindrical-shaped object. In the second stage, they understood that they should find out what the area of the base and the height of the pond were.

Figure 3 Example of the result of students’ work on the Bubakan roundabout task

Nevertheless, they had difficulty determining the area because they needed to know its diameter beforehand. One student remarked: ‘This is difficult because we have to get into the pool to measure its diameter’. After trying various methods, such as using sticks that extended into the middle of the pool, and still encountering difficulties, they finally found a way. In the third stage, they measured the circumference of the pond using poolside segments. Each segment measured 124 cm, and after counting, there were found to be 52 sections around the pond; thus, they obtained the result that the circumference of the pond was 6,448 cm.

In the fourth stage, using the formula circumference of a circle, they found that the radius of the circle was 1026.75 cm. This was used to calculate the area of the base of the pond and then multiplied
by the height of the water in the pond. They found that the volume was 264,815.04 liters. In the last stage, they used these results to answer the question on the real situation, i.e., on the number of bottles of water needed to fill the pond.

Since the volume of one bottle is 1500 milliliters or 1.5 liters, they divided the result by 1.5, giving 176,543.36 bottles. However, it is not possible to prepare 176,543 bottles and 0.36 bottles of water, so the result needed to be rounded off at 176,544 bottles. Finally, they obtained the result that 176,544 bottles of water were required to fill the pond, which was included in the interval of correct answers (between 176,000 and 177,000 bottles).

By observing the work of all groups in each task, we found that, in general, the problem-solving process performed by the students was in line with the stages of mathematization. Overall, 95.43% of work was shown for Stage I, 93.14% for Stage II, 90.24% for Stage III, 87.80% for Stage IV, and 80.18% on the stage V. We concluded that these data reflect the mathematical process in this activity.

5. Conclusion
It can be concluded that the math trails programme supported by the use of GPS-enabled mobile phone application has brought mathematics into the students’ worlds, and the students easily engaged in the activities. As a result, they were intrinsically highly motivated to participate in this fun, interesting, and challenging mathematics education programme. The activities resulted in an increase in student engagement in mathematics.

The students expressed engagement and enjoyment in the outdoor learning situation and interest in the use of an advanced learning tool. Here, students learned and experienced mathematics-related problem-solving using their prior knowledge. They practiced extracting information from the problems faced and used the mathematical concepts with which they were already familiar to solve those problems.

Schools can take advantage of the programme of this project by integrating it into the process of teaching and learning mathematics. The public can also participate in this programme for leisure by walking, with their family or friends, around the city while learning mathematics at the weekend or during the holidays. They can use the existing trails or contribute to designing new ones by following the steps that have been taken in this study.

As a pilot study, the research was restricted to one city. Although it has provided information on the overall project implementation and provided suggestions for models of development, further research needs to be conducted to determine the development of this project in other places or cities with different conditions.

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