Basic Numbers – Application to Support Gamified Teaching of Basic Numerical Operations at the First Stage of Primary School with Options for Remote Online Teaching and Blended Learning

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Abstract

The multiplatform app, Basic Numbers, was developed to practice basic math operations. It is therefore intended primarily for students in the first stage of primary school. Basic Numbers combines the main advantages of competing applications, but also brings some innovative features of its own to make teaching, self-study and testing in the subject more effective. In addition to the classic setting of numerical operations and the range of members of the generated problems, it allows complex definition of the overall structure of the problem so that the assignment suits the various types of tasks. Continuous monitoring of solution results brings elements of gamification. Basic Numbers also supports an online mode in which the teacher can prepare an assignment for students to training of knowledge on their devices. The teacher can then simply give the students a short unique code that makes the assignment available to them under the set conditions, and they can practice solving the generated problems independently. The application then sends the results of their efforts via a cloud server back to the teacher's device, giving them feedback that can help them adapt their lesson plan. The application can also be used for formal testing, both remote and in-person. It is possible to set restrictions on switching between apps. The development of the app is still ongoing, but in its current version it is already proving to be a solid and useful tool for a modern way of effective teaching in the field of basic mathematics.

Keywords

Mobile Learning, Primary school, Mathematics, Gamification, Testing, Blended Learning.

INTRODUCTION

The Basic Numbers application was created as a tool for practicing basic mathematical operations, especially for first grade primary school students. It has unique setting options for generating random problems, thanks to which it is possible to prepare practice and testing of various types of tasks with elements of gamification (Hubálovská and Hubálovský, 2016). The examples are marked with coloured icons, each step is accompanied by sound effects and there are also step-by-step hints, which, however, take away the stars in the rating on the individual example pages (see Fig. 8). Another useful feature that was added

during the quarantine of COVID-19 is the option to test students online. No competing application yet has such detailed options for setting up an example generator in combination with the possibility of online pupil testing. The Basic Numbers application can be used by students and teachers on Android smartphones, but is also available on Windows 10 devices, i.e. PCs, laptops and tablets.

METHODS

The Basic Numbers application was created in the Xamarin.Forms multiplatform technology (Hermes, 2015). This allows the development of native apps for Android, iOS[1] and Windows operating systems through a single common code in the C# programming language, and the XAML markup language, which allows for a single design definition (Voborník, 2020). SQLite (Winslett and Braganholo, 2019) is used as the local database on the end-users' devices, while the central (cloud) database on the server is provided by SQL Server (Bernstein, et al., 2011). The server part of the application was then created in ASP.NET Core 3.1 (Lock, 2021) and gradually updated to newer versions, with custom implementation of secure API communication. Data transfer is secured by the https protocol with a secure SSL certificate and token-based authentication via ASP.NET Core Identity.

The generation of the input problems is provided by a custom algorithm based on backtracking (Civicioglu, 2013; Coufal, et al., 2021a). It proceeds from left to right, i.e., by generating individual members and selecting operators between them (there can be more than just two members in the example). Everything is done completely randomly within the chosen bounds, but the constraints for the intermediate computations and the overall result are constantly monitored. Thus, if a newly added member exceeds the constraints for the result between calculations, it is immediately replaced by another (Coufal, et al., 2021b). If it fails to find a suitable member within a certain number of attempts, the generator backtracks one step, tries to change the operator between the members, and repeats. If even this change does not work within a certain number of attempts, the generation is returned one order of magnitude lower, i.e. to the previous member of the problem input (Coufal and Trojovský, 2021). To verify the result of the generated examples, the same algorithm for evaluating mathematical expressions as in the Algorithms program (Voborník, 2007) described in (Voborník, 2006) was used (Voborník, 2019). The generation of examples takes place on the client side, thanks to which the server is not unnecessarily burdened and it manages to handle more requests.

RESULTS

The main result of this work is primarily the Basic Numbers application itself. Secondary results are the extension of the possibilities of improving children's knowledge in the field of basic mathematics. Another positive benefit is also the option of using the application in lessons, which would lead to its diversification, gamification and, for example, in the case of real testing, to facilitate the work of teachers and the implementation of the Strategy for

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[1] Version for iOS was not released yet, because it is closed system and requires a Mac for debugging and compiling, which author of the app doesn't own.

the Education of the Ministry of Education, Youth and Sports of the Czech Republic (MŠMT, 2020, p. 31–33; Němec, 2019).

History of development

The basic feature of the Basic Numbers application is that it generates sets of random examples based on the set criteria. In the first phase, it was possible to define a range for the individual members of the examples and of results, and also a range of intermediate calculations for problems with more than two members. To support real-world testing, protection against application switching (so that the student cannot switch to a calculator or chat, for example) and the ability to lock settings with a password were also added later (version 1.2). This functionality has already been described in (Voborník, 2019).

In April 2020, the app was expanded (version 1.3) to make it usable for home teaching of primary school students during quarantine measures due to the COVID-19 pandemic (Němec, et al., 2020; Jahodová Berková and Němec, 2020). The application settings have added the option to define ranges for individual members of problems and also the so-called control conditions. These conditions are logical expressions written in a simple mini-language (Tab. 1 and Fig. 4), and are used to make the examples generator settings even more specific to suit various task types[2]. Parents could then set the app to generate sets of examples exclusively for the currently discussed material during maths lessons at home (Voborník and Němec, 2019). Pupils could then practice independently and, thanks to the feedback provided by the app, work according to their individual needs until they had mastered the material.

Table 1: Examples of control conditions for classic problem types.

Types of examples	Range A	Range B	Control condition
Subtraction to 100 with transition over 10	21–99	2–9	A % 10 >= 1 & A % 10 < B
Addition to 100 with a transition over 10	11–99	11–99	A % 10 > 0 & B % 10 > 0 & A % 10 + B % 10 > 10
Addition and subtraction to 100 of double-digit numbers, where one of them is a multiple of ten (the second for subtraction)			AB='+' & (A%10=0 & B%10>0 | A%10>0 & B%10=0) | AB='-' & A%10>0 & B%10=0
Integer division to 100	2–100	2–50	A % B = 0 & A != B

Over time, however, another need emerged, namely to shift the necessity of setting the application to the appropriate types of problems, controlling the frequency of practice and assessing the level of knowledge of individual students back to the teacher. Although they could have prepared the setup, sent instructions to the parents and then had them send, for example, a screen shot with a list of the tests that had been run, such a process would have placed an unnecessary burden on the parents and left room for potential errors. For this reason, support for online testing was added in the next version (1.4), which allows

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[2] The mini-language for determining the conditions of the example generator can be difficult for someone, but these settings can already be passed on using a test code. In the future, it is also planned to prepare a website with a database of these codes for various type settings of examples discussed in primary schools.

teachers to have complete control over the entire assignment and assessment process, giving them many additional options, including support for remote assessment, and making things easier for parents, who only need to supervise students/children working independently (Hubálovský, 2013).

Online testing

The process of online testing of students by teachers through the Basic Numbers application since version 1.4 is summarised in the following diagram (Fig. 1) and its description.

1. **The teacher prepares a test**, i.e. settings for examples generator and under it the time limit as well as setting the conditions for its completion.
2. **The teacher sends the test to the cloud server**, obtaining its unique **code**.
3. The teacher will **distribute this code to the students** via any channel (e-mail, Microsoft Teams, WhatsApp, Skype, Messenger...), or give it to the students in some other way (publish it in the school LMS system or on the web), or write it in the classroom on the blackboard if it is a full-time examination.
4. **Students launch the online testing function in the app**, where they enter the test **code** and the test parameters specified by the teacher are downloaded from the cloud.
5. Students **complete the test** on their mobile phone or computer.
6. **Test results** (total score and analysis of individual examples) are **sent** to the cloud.
7. **The teacher downloads the students' test results** from the server to their device. The teacher can then export the results to MS Excel.
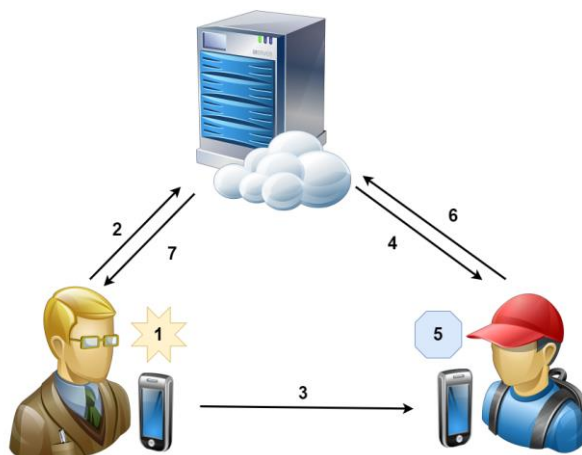

Figure 1: Flowchart of communication during online testing.

Teacher's procedure

While for online testing, the student only uses the last button (Test) instead of the first button (Start) in the initial menu, the student enters the code and then starts the test immediately, the teacher works with three types of records, hierarchically arranged under each other (Fig. 2). These are the conditions **settings** for the problems generator, **the tests** with the given settings and **the results** of the given test from each student.

You can switch to teacher mode by clicking the less prominent three dots button on the right side of the top bar on the app's home page. The first time you use it, you need to either log in or register. The teacher is then taken to the first overview with the example's generator settings.
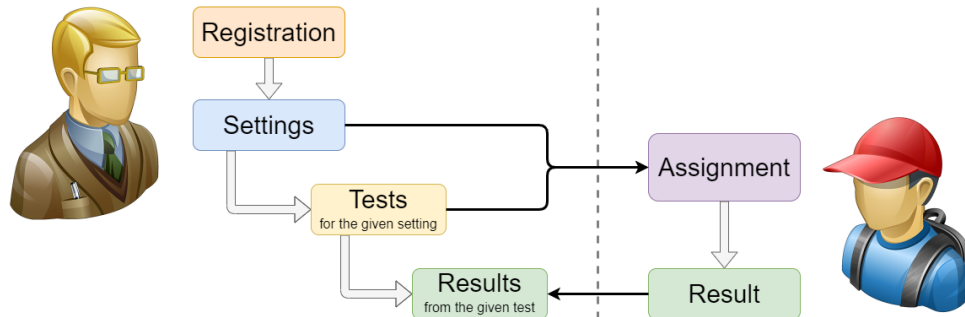

Figure 2: Flowchart of navigation in the application during online testing.

Settings

The overview of settings is initially empty until the teacher creates some, or downloads from the server the settings they created earlier on another device by calling synchronisation. After selecting a setting, the row with it in the overview is highlighted and additional icons for working with the selected record appear in the top panel (Fig. 3).
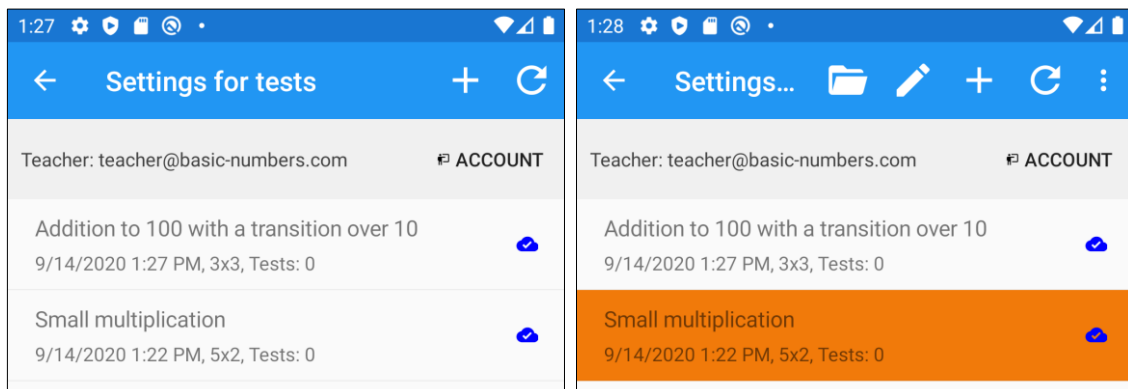

Figure 3: Overview of problems generator settings.

When creating a new setting or editing an existing one, a form identical to the one available in the main part of the application opens (Fig. 4). The only thing missing here is the option to lock the settings with a password, because the student cannot affect the settings for the online test, and if the student were to download the password-protected settings and save them as the main settings, this would lock the ability to change them later.

After leaving this page, it will first attempt to generate problems in the background for the set assignment, and if this fails, the teacher will be prompted to first modify the generator conditions. If successful, it continues by automatically saving the settings to the device and also to the cloud server.

If the device does not currently have an internet connection, the settings are only saved locally on the device and can be resent to the server later. Settings that are synchronized

with the server are marked with a blue cloud icon with an OK symbol in the overview on the right, while settings that have been changed and not sent to the server have a grey crossed-out cloud icon. To upload, just open the settings for editing and close them again, or use the button for two way synchronization of the entire overview of settings in both directions. When the settings is changed, the newly started tests will be generated with the new settings, but the records from the test results already generated will not be changed.
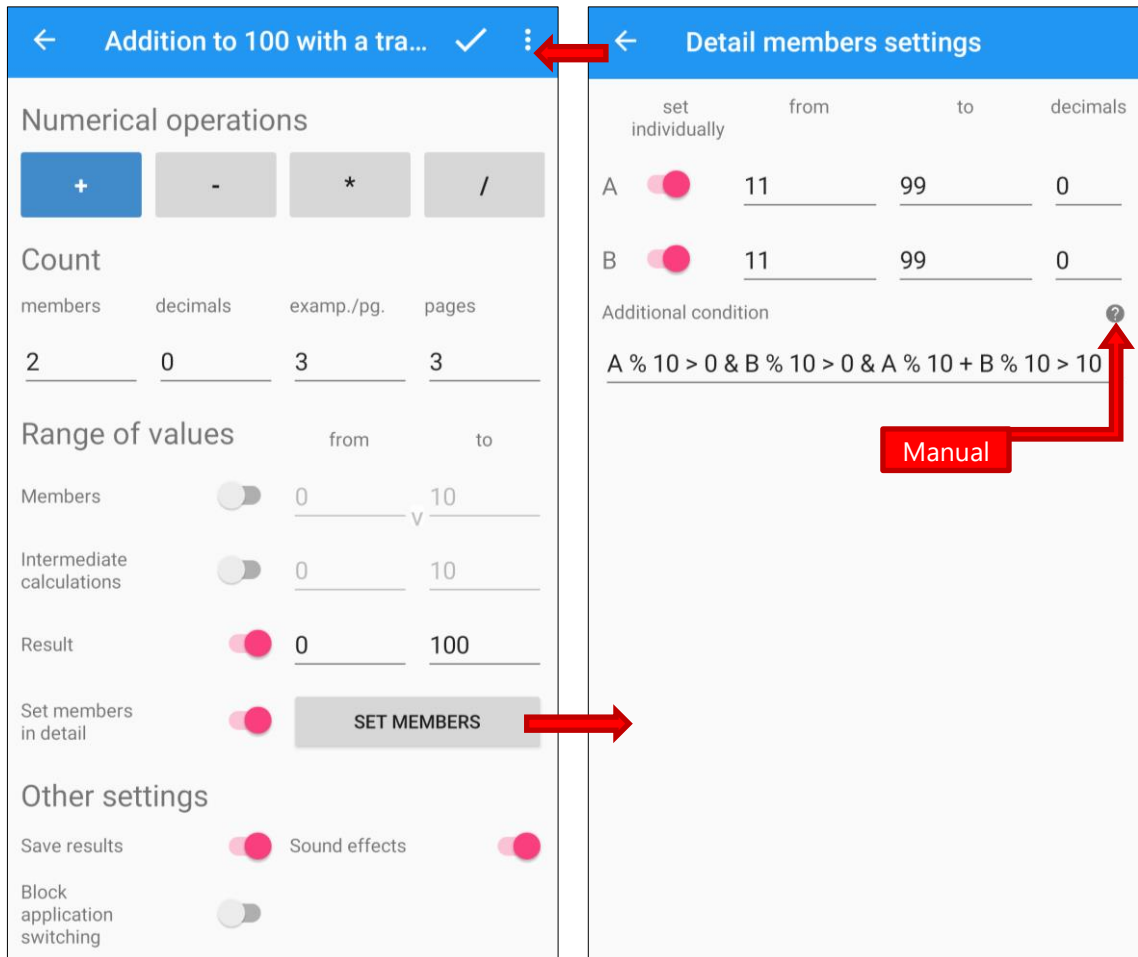

Figure 4: Overview of problems generator settings.

Tests

Selecting a setting and clicking the *Tests* button will then display another page with an overview of the tests for that setting. The name of the selected setting under which the tests fall is listed below the top panel. The controls here are the same as in the settings overview. You can create a new test, load tests from the server, or synchronize unsubmitted changes in these tests (Fig. 5).

On the page for creating a new test or editing an existing one (Fig. 6), you can define the name of the test (by default it is taken from the name of the test settings, which is also listed below the form), the instructions for the test, limit or not to limit the date and time from which the test will be available, limit or not to limit the date and time until which the results of the test can be saved, and if these results should be saved on the server at all. If the results are stored, from a GDPR perspective (Albrecht, 2016), you must also set a date

by which they will be stored on the server and after which they will be automatically deleted, with a maximum storage period of 1 year. The option to *Allow take settings* allows students (but not only them) to copy settings from a test whose passcode they know into their application without necessarily having to run the test at all.
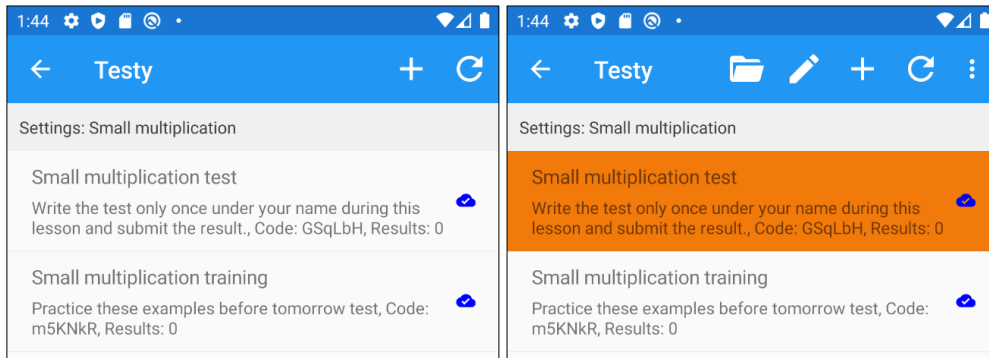

Figure 5: An overview of tests falling under the selected settings.

After the test is saved and sent to the server, a unique code is assigned to the test, which is displayed in read-only mode the next time the test detail is opened. This is the code students need to run the online test, so there is a button to quickly copy it to the clipboard or share it using the app of your choice on your device. This also allows you to share test settings between teachers.
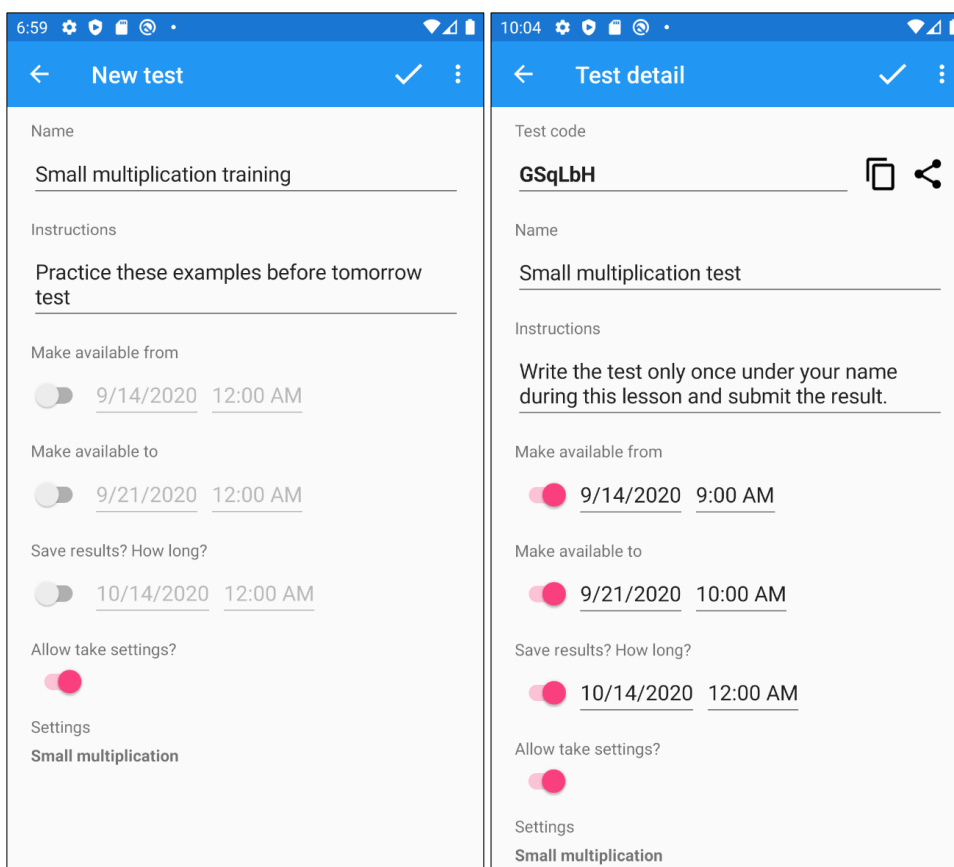

Figure 6: An overview of tests falling under the selected settings.

Results of the test

Selecting a test and clicking on the *Results* button will then display another page with an overview of the results from that test (Fig. 7). For each test, you can already see the name of the student or the designation the student entered before the test, the date the student sent the result to the server, the total time (minutes and seconds) the student spent on the test and the total score the application gave to the student's performance.

This time, the cloud icon indicating the synchronization status indicates that the last time the data was restored, the status of the result stored on the server and on the device was the same, or that the result downloaded to the device was deleted on the server. The deletion can occur either automatically when the deadline for deleting the result is reached (set in the test details, maximum 1 year) or by the student from his/her application, who has the right to delete his/her assessment from the server at any time in terms of GDPR. However, a copy of the result remains on the teacher's device until they delete it as well. In fact, the teacher can also delete the results from both his device and the server in the extended menu, but if he has used more than one device, the result can still be stored on the other device.

Figure 7: Summary of results from the selected test.

A list of all test results currently downloaded on the device can be exported to CSV format (e.g. for MS Excel) using the button in the extended menu. For this export file, the classic file sharing menu opens, so that you can, for example, send it to an e-mail or save it in another folder of the device or in your own cloud service.

After selecting one of the test results in the overview, you can also open its detailed breakdown. The teacher can then see the problems that were generated for the student in this test according to the conditions the teacher set, what the correct solution was, what variations of the result the student tried before successfully completing the page with the examples and how many motivation stars the student received for the given set (page) of examples (Fig. 8). Students can also view the same detail analysis of their test on their facilities.
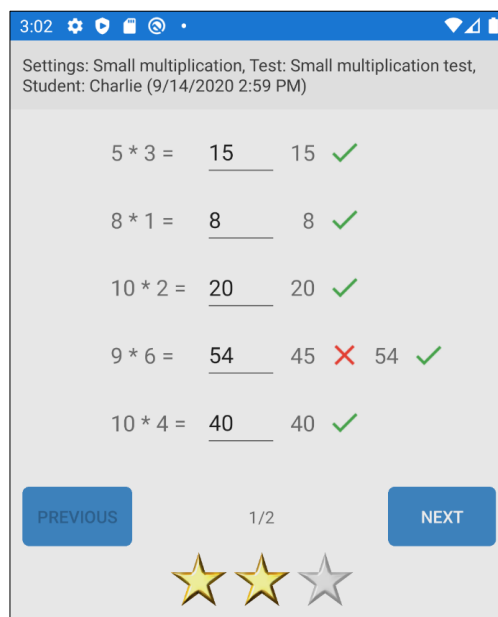
Figure 8: Detailed analysis of the selected test.

CONCLUSION

Together with previous versions of the application, such as the option of defining control conditions for the generated examples, which allow to specify virtually any type of assignment, or the protection against application switching, the option of online testing provides great variety of uses not only for teachers.

For example, teachers can prepare sets of examples for their students to practise both at home and in class (blended learning), they can continuously test their progress on different types of assignments, remotely and in the classroom for full testing, where teachers can ensure that pupils don't cheat, while taking full advantage of the automatic generation of unique assignments, as well as automatic scoring and results collection. The remote testing capability can then be of great benefit to students who are absent for long periods of time or during quarantine measures.

It is not strictly necessary to use just a mobile device for preparation and control, but there is also a Windows version of the app that can be used to control everything conveniently via a PC or laptop, while ensuring full synchronisation of all data between all devices.

At the same time, teachers can send settings they have already created to each other, thanks to the *Download Test Settings* function. Simply create a test for a given setting where this option is enabled and provide the code to your colleagues. Instead of running the test under this code, they can copy the settings to their device and, by saving and loading them, transfer them back to their own tests, either in their original or modified version.

In the application, the assignor of the tests is referred to as a teacher, but this is only a role under which anyone can register, including, for example, parents of students, friends or tutors who want to help them with their elementary mathematics studies, can prepare various exercises for them remotely and analyse their results with them.

In the next version, it is also planned to be possible to transmit (display, send, share and retrieve) the access code to the test using a QR code and administration of groups (classes) of pupils, to whom it would be possible to enter tests even without a code.

ACKNOWLEDGMENTS

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