A MOBILE GAME-BASED LEARNING SYSTEM FOR PRIMARY SCHOOL MATHEMATICS

Margarita Gocheva, Nikolay Kasakliev, Elena Somova*

University of Plovdiv "Paisii Hilendarski", Plovdiv
Bulgaria

*Corresponding Author, e-mail: gocheva@uni-plovdiv.bg

Abstract: The paper presents the development of a prototype mobile application suitable for children in the primary school stage using the approaches of game-based learning, adaptive learning, micro lesson learning, and behaviour-monitoring learning. The general architecture of a system for mobile game-based learning based on modules is presented. A mobile game design based on templates is proposed. Several software tools were used to implement the mobile application. The prototype was tested in a real learning environment.

Keywords: game-based learning, mobile learning games, adaptability

1. INTRODUCTION

The 21st century is a century of rapid development of information and communication technologies (ICT). An era in which society uses modern technology constantly. Rapid changes in the development of technology also affect the field of education. Online teaching and learning are increasingly being implemented. Mobile devices provide great opportunities for learners to learn anywhere and anytime, without limitations in acquiring new knowledge and skills. Smartphones and other mobile devices provide many advantages when used for learning: accessibility, personalization, own pace of learning resources, easy communication and collaboration with other participants in the learning process, etc. Mobile learning (m-learning) makes learning more interesting, flexible and accessible and removes traditional limitations.

On the other hand, games are an important part of every child's life. Games are especially inherent in childhood when a person is more subject to learning and upbringing. Therefore, the game approach is fundamental in the teaching methodology of children of preschool and primary school age. Pedagogy has long emphasized the role of games in learning and education, through which children acquire new knowledge and skills while having fun. Educational games include elements that make them a powerful motivational tool for learning. Combining m-

learning and games can create an interesting learning and entertainment environment.

The purpose of the study is to present a developed prototype of a mobile game-based learning system suitable for primary school children. The proposed mobile game application was intended for learning mathematics in the 3rd grade, which could be applied alongside traditional learning in a classroom or at home.

Section 2 shows the state of the art in the field of modern innovative learning approaches. Section 3 describes the model of mobile game-based learning and the selected approaches to implement the learning. Section 4 describes the developed mobile game application for primary school students. The architecture of the m-learning system and the technical and software tools for implementation are presented. The paper ends with a conclusion which focuses on the contributions of the study and the future plans of the authors.

2. MODERN LEARNING APPROACHES

In the modern world, education follows the rapid pace of technological development. Software systems are used to manage e-learning, specialized tools for developing digital educational resources, applications for synchronous and asynchronous communication that shorten the distance between learners and trainers, etc. To minimize costs, more and more learning activities and resources are hosted in the cloud [1, 2]. Attempts are being made to build free private clouds on low-power consumer devices [3]. The use of cloud services is applied to support mobile learning [4]. Mobile games are being developed to engage learners' attention and make learning more fun, etc. Learning forms such as **m-learning** are becoming more and more popular. M-learning helps students create social interaction, promotes collaborative learning, and improves their learning, achievement, and motivation [5]. **Games** are integrated into learning in various forms: game-based learning [6], gamification, simulation games [7], mobile educational games, etc. Mobile educational games, unlike other games, in addition to offering fun, should be able to capture children's interests and make them think logically, think spatially, draw conclusions, make connections to their daily lives and apply what they learn in school.

M-learning can be very effective in learning mathematics, and there have been many authors working in this area. [8] designs and develops a mobile app called Hi-Math as a game-based learning experience for children in 3rd grade aimed at acquiring basic numeracy skills. According to [9], mobile games reveal learning material in an interesting way - images, sound effects, and movements complement each other in an attractive way, making the student active, effective, and willing to learn.

Adaptive e-learning is a modern educational approach that is designed to provide a unique e-learning environment suitable for the needs of each student. The aim is to identify the specific needs of a learner and to implement an appropriate

pedagogical strategy to improve the learning process. The main characteristics of adaptive learning are flexibility, motivation, engagement, personalization, adaptation, feedback, accessibility, etc. The literature most commonly refers to three types of e-learning system adaptability [10]: user interface-based adaptation, learning flow-based adaptation and learning content-based adaptation. [11] presents an adaptive mobile learning system that provides learners with adaptive content according to their knowledge levels, learning styles, and heterogeneous learning devices. A learning game is developed by [12] – an adaptive mobile game for pupils of the 1st, the 2nd and the 3rd grade for practicing their skills in the multiplication table.

As part of the adaptive learning process is the adaptive assessment applied in **Computerized Adaptive Tests (CAT)**, which adapts the complexity and number of test questions to the learner's level, to obtain greater accuracy in the assessment. For example, [13] presents the Adaptive Formative Assessment in Context-Aware Mobile Learning approach, where the goal is to provide learners with an adaptive and personalized assessment taking into account the learner context based on the CAT theory.

Micro learning is becoming a very popular learning trend. It can be defined as very short and bite-sized lessons lasting no more than 5 minutes [14]. Authors [15] believe that mobile micro learning applications are more effective, flexible and enjoyable.

3. MODEL OF A MOBILE GAME-BASED LEARNING

A common model of mobile game-based learning suitable for primary school children has been created. The model is based on a cyclical learning path containing the following steps:

- **Practice** – learners solve problems presented as games;
- **Grading** – solved problems are graded automatically;
- **Rewarding** – different "bonuses" are received based on the evaluation;
- **Support** – learners receive support when they first fail to solve a task type;
- **Micro lessons** – learners receive micro lessons when repeatedly failing to solve a given problem type;
- **Ranking** – learners are ranked at the end of the game.

The **learner model** is formed based on three sub-models: a **learning model** (learning achievements), a **game model** (in-game achievements), and a **behavioural model** (in-game reported data about the learner's behaviour).

A **formal model** of mobile game-based learning has been created, which is the triple *(G, S (d, t), A (d, t))*, where *G* is the set of learning objectives, *S* is the set of learning resources, and *A* is the set of learning activities, which depend on *d*, the difficulty level, *t*, the time to implement the learning with the corresponding item.

The **approaches** that have been chosen to be applied in the implementation of mobile learning for the primary stage are **game-based learning, adaptive learning, micro lesson learning and active learning through behaviour monitoring**.

As a next step, a **classification of the types of game tasks** (games) suitable for mobile implementation is made, supporting the teaching of mathematics to primary school children [16]. The classification contains 13 types of game tasks divided into 8 categories: Multiple choice, Alternative answer, Multiple answers, Ordering objects, Matching, Filling in fields with multiple choice, Filling in fields in a template and Open answer.

To implement the first approach, a study of the game elements and techniques that exist in games and can be applied in mobile learning [17] was made. It shows the experiences and emotions of the players before and after using the game elements and techniques.

The application of adaptability is implemented both in the case of learner failure and in the case of success. The adaptability offered is based on: different types of tasks arranged in game levels, the difficulty of the tasks, the success/failure of the learner and the time to solve the game tasks. The model is built to implement **adaptability of learning content and adaptability of learning process.**

A mobile educational game with embedded micro lessons can be a successful learning tool, especially for primary school students. In our mobile game model, short text hints are provided on how to solve the problem (on the first failure), on the second failure at the same level of the game – a video example (micro tutorial).

Didactic, behavioural and functional models are proposed that can be used to create both a stand-alone game application and a mobile game platform.

The **didactic model** allows the achievement of pre-set pedagogical goals in the application of game-based adaptive learning, consistent with state educational requirements and modern pedagogical approaches.

The **behavioural model** looks at the emotions and aspects of the child's behaviour during play that could be detected and analysed like in [18].

The proposed **functional model** includes a description of an interaction model (of the participants in the learning process) and a synchronization model (of the data in the representation of a global ranking for all participants in the game). Two main roles stand out – the student and the teacher.

During a game, players' scores are recorded in a local database. When the game is played by multiple participants on different devices, anywhere and anytime, the need for synchronisation of results arises. For this purpose, in the proposed model, an approach using web services is chosen. Mobile applications send requests to the web server. The received requests are processed by the web server, which communicates with the server database. The data is sorted by specific criteria (according to the query) and returned as a response on demand to mobile devices. In the proposed model, the ranking data is also visualized in a web application. From it, the teacher will have access to all the information about the players.

4. A MOBILE GAME-BASED LEARNING SYSTEM

To build the software prototype, several software modules have been implemented, which are an integral part of the overall architecture. The architecture of the developed prototype contains a "Game Environment" module with several components (layers) that directly interacts with the "Synchronization" module, which in turn interacts with the "Reports" module (Figure 1.).

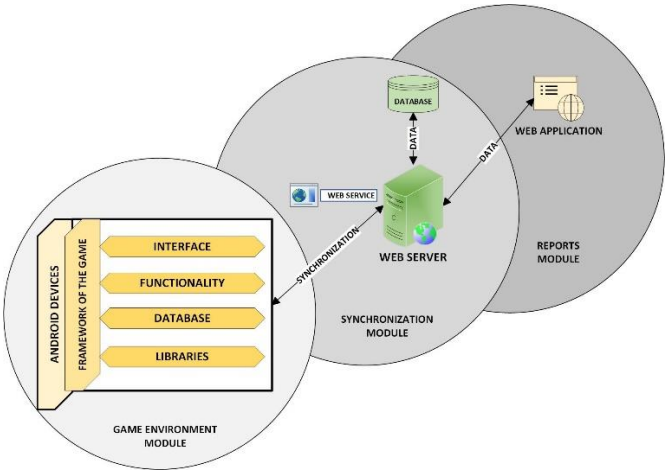

Figure 1. The general architecture of the mobile game-based learning system

The **"Game Environment"** module is a game type Android application.

The **"Synchronization"** module implements a process in which participant scores and game data are sent to a web server where they are processed and sent back to the mobile devices to synchronize the data from all players.

The **"Reports"** module contains processed information obtained from the synchronization module in the form of various sorted data lists that are available to the teacher for evaluation and analysis.

4.1. "Game Environment" module

The game environment module represents the main module of the overall development of the mobile game-based system. The module implements a game environment designed for primary school children (3rd grade) and develops mathematics skills. The module is implemented as an Android application and is a project that contains multiple Java classes. The mobile app architecture contains several layers that are interconnected, interact with the Android structural framework, and function as a whole.

The **"User Interface" layer** – implements a graphical interface that visualizes all elements of the game.

The process of designing and creating the game design goes through two stages – creating sketches and creating templates on each screen.

During prototyping, an experimental app model is created that presents ideas of what the game would look like – **sketches** with an arrangement of the elements that each screen of the game would contain. Based on the classification of task types [16], 8 of them were selected for mobile implementation. They represent the 8 levels of the game, which contain mathematical problems (missions) to solve.

Figure 2. Problem implemented by the template "Multiple answers from images" – level 3 of the game

For the sketches at each level, a child-friendly interface is proposed for children to design corresponding templates (Figure 2.). Thus, the game design is based on **templates** [19] and is tailored to the age of the target group – it is colourful and fun. The images in which the tasks are generated are selected and specific game elements are chosen to be used in each level: bonuses (coins), rewards (gold bars), timer (related to the combo), badges, etc.

The **"Functionality" layer** contains all the functionality representing the game logic. For the implementation of the prototype of the mobile educational game, a standard approach is used – based on levels. The game consists of 8 levels. The learning activities are implemented through **missions** – mathematical tasks that are randomly generated by the system.

There are **3 types of difficulty (1, 2 and 3)**. The game starts with medium difficulty (2) and **a target time** (60 seconds) for each level. An **adaptive methodology** is applied depending on the correctness of the answer, the difficulty of the mathematical problem and the time to solve it. Students form an **individual learning path** that is unique to each due to the application of the adaptive approach [20]. In case of wrong answers, students receive **support**: a hint on how to solve the problem (short text with guidelines) on the first failure, and a video example in the form of **a micro lesson** on the second failure at the same level of the game.

The rewards system gives many incentives to students: bonuses, rewards, badges, combos, etc. For correct answers, students receive bonus coins that are different for each difficulty level: 2 coins for medium level, 3 coins for high level, 1 coin for low level and 0 coins for failure. For every 6 coins, students receive 1 gold bar as a prize. Any unused time in completing one mission is saved and offered as a

combo (extra time) in solving the following tasks. The game ends with the **final ranking**.

Once the game is completed, each participant's data is sent to a web server. The data is synchronized and presented in the form of rankings to provoke the competitive spirit in the learners. Sorted data is returned to mobile devices (on demand) and sent to a **web application** for use by the educator.

The web application provides the tutor with data reported during the game. The application receives information about the final game scores of the students as well as information about the behaviour of the players during the game.

The mobile application is implemented with Java programming language. Multiple classes and methods are defined to implement the game flow. On the other hand, *XML* was used to define the user interface structure of the application. All 8 activities (8 levels) of the game are developed based on the made templates. The interface of each activity is defined using a layout file via *XML* code.

The **"Databases" layer** contains the game DB where the game flow data is stored. The database of the implemented prototype contains 9 tables. When the game starts, the player's name and chosen avatar are saved. The current start date and time of the game as well as the end date are also recorded. During the game, data is stored about the level reached, current points and rewards won. The time spent at each level is also reported in the DB as it accumulates for the final time score, and the remainder of the unused time from each level is carried over to each subsequent level. Information is also stored on the number and type of prompts for failure (first and second failure in a level) and at which level the support was received.

Data recorded by the mobile device regarding the player's behaviour, such as the number of switches to other applications during the game, the decibel noise level during the game, sudden movements of the mobile device, and whether the player's device is connected to a wireless network and the Internet, are recorded in the DB. From this data, a **behavioural model of the player** can be constructed.

In the **"Libraries" layer**, the standard *Android Studio* library *Gradle Scripts* was used in the prototype development. Each *Android* project uses *Gradle* to generate an installation package – an *apk* file from the *.java* and *.xml* files in the project. To enable the transfer of data to the web server, another library, *Volley*, has been added to enable reliable data transfer to the web server.

4.2. "Synchronization" module

After the game is over, each player should be able to see how they did against all other players (global leader board) in addition to a local leader board. The developed mobile application uses a web server (*Apache HTTP server*) to **synchronize data**. Of the mobile applications that are in the so-called **client (user) layer** of the architecture (Figure 3.) requests are sent to the web server using the *HTTP* data transfer protocol. Internet (connectivity) is required during the game for successful submissions. The received requests are processed by the web server in the so-called **server layer** of the presented architecture. *MariaDB* database, independent

development of *MySQL*, was used to store the server data in the so-called **storage layer**. The data is sorted by a specific criterion and returned as a response on demand to mobile devices. Finally, a synchronized ranking is displayed for all participants on the user's mobile devices. For remote data storage in the server DB, 8 tables have been created. These tables are equivalent to the tables in the local database and record the data reported during a game. The recorded data is used in the synchronization of the final ranking, as well as in the invocation of various reports by the teacher.

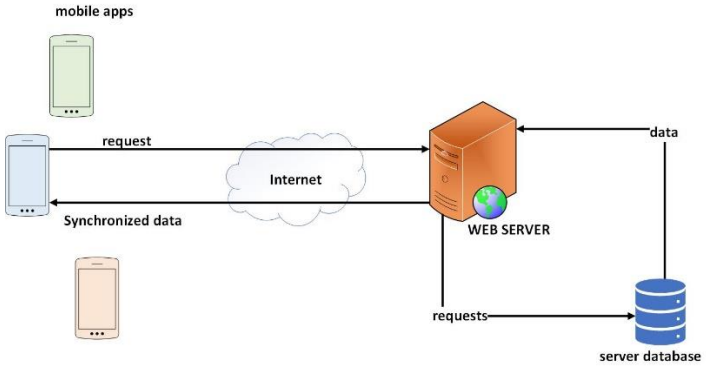

Figure 3. Synchronization module architecture

4.3. Module "Reports"

The "Reports" module is a web application for the teacher to track and control the learning process. The developed web application aims to provide access to all recorded game data to students during and after the game. The architecture of the application follows the client-server model. The transfer of information between the web browser and the web server is done using the *HTTP* protocol. The developed web application has a responsive design.

After logging into the web application, the teacher has various reports available during and after the game:

- **General Ranking** – presents a ranking of the players containing name, time and points. The displayed data is sorted first by the number of points and second by time (if the number of points matches).
- **Support received** – shows a report for all learners with their number of hints received (1st and 2nd) and at which levels of the game they were received. The tutor can see which math problems each student struggled on and get help accordingly;
- **Game duration** – provides a reference with the current start and end date and time of the game for each player.
- **Connectivity to networks** – indicates whether learners' devices had access to a wireless network and the Internet;

- **Player behaviour** – this report brings together the following information about players:
  - Switches to other apps during game play – report the number of times the student was distracted by other apps;
  - Enhanced noise level – the noise level is measured continuously during play and is reported when the noise above 40 decibels is detected;
  - Movements of the mobile device – the sudden movements of the learner's device are detected.

4.4. Implementation of the prototype

Android is the most used OS for mobile devices in the world. The possibility of open architecture, multimedia and graphical visualization and a rich set of user interfaces, gesture and touch controls, make Android a much-preferred platform for mobile devices and highly suitable for developing and deploying m-learning applications [21].

The following technical tools were selected for the prototype implementation:

- *Android Studio* for the development environment, version *Bumblebee | 2021.1.1 Patch 3* for *Windows 64-bit* with *Java*;
- DB *SQLite* for local runtime data storage;
- *Apache HTTP Web Server* for remote storage, including synchronization;
- DB server *MariaDB* for remote data storage;
- *PHP* version *7.4.29* and *HTML 5* for web application development;
- *Microsoft Visio* for the prototyping process;
- *Filmora Video Editor 11* for creating micro tutorials, which are short video clips.

4.5. Experiment

The prototype has been tested in a real classroom environment with 17 students in 3rd grade and 10 teachers from Yane Sandanski School, Plovdiv, Bulgaria. All participants initially tested the game and then completed a survey (the response rate was 100%). The survey with questions (different for students and teachers) was conducted to gather opinions, impressions, and recommendations. The research methodology is based on surveys designed with *Google* forms. The survey questions are divided into the following six sections: “Practical applicability”, “Motivation”, “Design”, “Accessibility”, “Support and feedback”, and “Open-ended questions”.

A part of the students’ results: the "Practical Applicability" category shows that 94.1% of learners would prefer to use a mobile game in a math class. All (100%) students respond that they like learning through a mobile game and would play it at home. In the category "Motivation" all students (100%) expressed the opinion that they like mobile game-based learning. 94.1% of them shared that receiving awards motivated them, and the remaining 5.9% – that it only somewhat intrigued them.

A part of the teachers’ results: according to the category "Practical Applicability", all teachers believe that gamification is suitable for use in

mathematics lessons at the primary stage (60% strongly agree, and 40% – agree). Absolutely all teachers believe that the game approach supports the effective achievement of educational goals in mathematics at the primary stage. Teachers think that the learning process supported by the mobile game develops students' learning skills (60% of teachers strongly agree and 40% agree). They also support adaptability as a good methodological approach in this age group (80% answered that they agree strongly and 20% just agree). Category "Motivation" shows that all teachers believe that the learning process supported by the mobile game awakens students' interest in mathematics (80% strongly agree and 20% just agree).

5. CONCLUSION

The created game-based learning system is accessible from all types of mobile devices, facilitates mathematics learning and provides learners with another environment of learning resources and activities accessible anywhere, anytime. The game is interesting, fun and encourages/challenges the learner to solve different problems to improve their knowledge of mathematics. Adaptability is a main distinguishing characteristic of the game. Built-in game elements motivate learners and reinforce the drive to achieve better results. The implemented game can be used for self-study at home by students or offered by teachers in class for an exercise. The data that is tracked and reported during the game is available to the teacher by being visualized in the web application, which allows convenient analysis of the game information. The collected data could be used not only by the teacher but also for future research aimed at implementing mobile learning based on games and studying the child's behaviour during play.

REFERENCES

[1] Hadzhikoleva, S., E. Hadzhikolev, S. Cheresharov, L. Yovkov. Towards Building Cloud Education Networks. *Tem Journal*, vol. 7, no. 1, 2018, pp. 219-224.

[2] Charkova, D. Evaluation of the Effectiveness of a Cloud-based EFL Writing Course against a 90% Mastery Threshold. *The Journal of Language Teaching and Learning*, vol. 12, no. 2, 2022, pp. 1-20.

[3] Cheresharov, S., G. Gustinov, S. Hadzhikoleva, E. Hadzhikolev. Distributed Public Cloud on Low Power Devices *21-st International Symposium on Electrical Apparatus and Technologies (SIELA)*, 3 - 6 June 2020, Bourgas, Bulgaria, pp. 50-53, ISBN 978-1-7281-4345-3.

[4] Kasakliev, N., E. Somova, S. Hadzhikoleva, Use of cloud services to support mobile learning, *International scientific online magazine "SCIENCE and TECHNOLOGY"*, vol. 4, 2014, pp. 94 - 98. (in Bulgarian)

[5] Mouza, C., T. Barrett-Greenly. Bridging the App Gap: An Examination of a Professional Development Initiative on Mobile Learning in Urban Schools. *Computers and Education*, vol. 88, 2015, pp. 1-15.

[6] Podjačevs, P., O. Skorobogatova. Computer role-playing games as one of the most efficient methods of teaching and learning in higher education. *International Journal on Information Technologies & Security*, vol. 9, Special Issue № SP1, 2017, pp. 65-78.

[7] Kasurinen, J., Kettunen, M. Learning Cyber Security: Teaching Technically Challenging Topics with Games and Virtual Laboratories. *International Journal on Information Technologies and Security,* vol. 10, no. 3, 2018, pp. 103-114.

[8] Yussop, Y.M., S. Annamalai, S.A. Salam. Hi-math mobile app: Effectiveness in improving arithmetic skills of primary school students. *International Journal of Recent Technology and Engineering,* vol. 7, no. 6, 2019, pp. 67-71.

[9] Alkhateeb, M. A. Effect of Mobile Gaming on Mathematical Achievement among 4th Graders. *International Journal of Emerging Technologies in Learning (iJET)*, vol. 14, no. 7, 2019, pp. 4-17. https://doi.org/10.3991/ijet.v14i07.10315

[10] Velsen, L. User-centered evaluation of adaptive and adaptable systems: a literature review. *The Knowledge Engineering Review Journal, Cambridge University Press*, vol. 23, no. 3, 2008, pp. 261–281.

[11] Ho-Chuan Huanga, Tsui-Ying Wangb and Fu-Ming Hsieha. Constructing an Adaptive Mobile Learning System for the Support of Personalized Learning and Device Adaptation. *International educational technology conference* (ietc2012).

[12] Leonardou, A., M. Rigou. An adaptive mobile casual game for practicing multiplication. *Proceedings of the 20th Pan-Hellenic Conference on Informatics*, 2016, DOI:10.1145/3003733.3003798

[13] Louhab, E. F., A. Bahnasse and M. Talea. Towards an Adaptive Formative Assessment in Context-Aware Mobile Learning. *3rd International Conference on Computer Science and Computational Intelligence, Procedia Computer Science* 135, 2018, pp. 441–448.

[14] Janke, I. Unpacking the Inherent Design Principles of Mobile Microlearning, *Technology, Knowledge and Learning*, vol. 25, 2020, pp. 585–619. https://doi.org/10.1007/s10758-019-09413-w

[15] Cates, S. et al. MobiLearn go: mobile microlearning as an active, location-aware game. *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, USA, New York, vol. 103, 2017, pp. 1–7. DOI:https://doi.org/10.1145/3098279.3122146

[16] Gocheva, M., E. Somova, V. Angelova, N. Kasakliev. Types of mobile educational games for children in primary school. *INTED2020, 14th annual International Technology, Education and Development Conference*, 2-4 March 2020, Valencia, Spain, pp. 2291-2300, DOI: 10.21125/inted.2020.0698

[17] Gocheva, M., E. Somova and N. Kasakliev. Game-based Approach in Mobile Learning for Primary School. *10th International Scientific Conference "TechSys 2021"*, Plovdiv Branch, 27-29 May 2021, AIP Conference Proceedings 2449, 070005 (2022), e-ISSN: 1551-7616. https://doi.org/10.1063/5.0090671

[18] Datcu, D., L. Rothkrantz. Face emotion recognition using a crisis related smartphone app. *International Journal on IT & Security*, vol. 13, Special Issue SP3, 2021, pp. 15-26.

[19] Gocheva, M., E. Somova, N. Kasakliev, V. Angelova. Mobile Math Game Prototype on The Base of Templates for Primary School. *Mathematics and Informatics*, vol. 64, no. 2, 2021, DOI: 10.53656/math2021-2-2-mob

[20] Gocheva, M., N. Kasakliev and E. Somova. An Attempt of Adaptability of The Learning Process and Content in Mobile Math Educational Game. *10th International Scientific Conference "TechSys 2021", Plovdiv Branch 27-29 May 2021*, AIP Conference Proceedings 2449, 070019, 2022, https://doi.org/10.1063/5.0090673

[21] Shanmugapriya, M., A. Tamilarasit. Developing a Mobile Adaptive Test (MAT) in an M-Learning Environment for Android Based 3G Mobile Devices. *International Journal on Computer Science and Engineering (IJCSE)*, 2012.

Information about the authors:

Margarita Gocheva, Assist. Prof., ORCID ID: 0000-0002-7739-5915, Department "Computer Science", Faculty of Mathematics and Informatics, University of Plovdiv "Paisii Hilendarski", 4000 Plovdiv, Bulgaria, E-mail: gocheva@uni-plovdiv.bg

Dr. Nikolay Kasakliev, Assoc. Prof., ORCID ID: 0000-0003-4010-144X, Department "Computer Science", Faculty of Mathematics and Informatics, University of Plovdiv "Paisii Hilendarski", 4000 Plovdiv, Bulgaria, E-mail: kasakliev@uni-plovdiv.bg

Prof. Dr. Elena Somova, ORCID ID: 0000-0003-3393-1058, Head of Department "Computer Science", Faculty of Mathematics and Informatics, University of Plovdiv "Paisii Hilendarski", 4000 Plovdiv, Bulgaria, E-mail: eledel@uni-plovdiv.bg

Manuscript received on 26 September 2022
Revised version received on 17 October 2022