A Review of Mobile Learning Applications for Mathematics.

http://dx.doi.org/10.3991/ijim.v9i3.4420

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***Abstract*—Mobile and online learning applications become more known year after year and are used today from millions of students and educators in all over the world. Wireless mobile devices like smartphones, PDAs and tablets, could be used to benefit students' learning in or out of the classroom. In front of the idea of inclusion of mobile learning in educational process, we represent in this paper some important case studies which examine the consequence of using mobile tools and apps, as well as online applications in mathematics teaching, at all educational levels.**

***Index Terms*—Mathematics education, mobile applications, mobile learning, online applications.**

I. INTRODUCTION

The last decades, mobile technologies, such as smartphones, tablets and laptops, as well as online applications and tools, became an integral part of the lives of most teachers and students in all over the world. These devices have transformed the way that people communicate, search for information and work. The challenge for the educators and researchers was to explore how mobile technologies might be used to support learning [10].

With the term mobile learning is meant the delivery of learning to students through the use of wireless internet and mobile devices, including mobile phones, personal digital assistants (PDAs), smartphones and tablet PCs [34].

Mobile learning is an area that develops very quickly and has been considered as the future of learning [24]. Mobile devices enhance anytime and anywhere learning, providing access to learning resources, even outside the school. This flexibility makes it possible for adult learners to minimize their unproductive time, which may enhance their work-education balance [25]. Technological progress can contribute significantly to the improvement and spreading of the use of mobile learning, as handheld devices become lighter, cheaper, with better screen analysis, longer battery life and faster network speed.

Naismith et al (2004) suggested a pedagogy-model-based classification of mobile learning with six categories: 1) behaviorist, 2) constructivist, 3) situated, 4) collaborative, 5) informal and lifelong learning and 6) support for learning and teaching [23].

In recent years, researchers developed online and mobile applications to support teaching in Algebra, Geometry, Mathematical Analysis, Statistics and other areas of mathematics. Mobile math applications allows users to explore functions, providing graphical capabilities and offer many kinds of specific calculators. There are apps designed to handle measurement tasks and educational apps for practicing on numerical and mathematical skills. Technologies that provide support for mathematics on the web have also been increasing over the last decade. Online and mobile educational tools for mathematics can assist students' problem solving, enhance comprehension of mathematical concepts, provide dynamically representations of ideas and encourage general metacognitive abilities [29]. The frequent use of mobile technologies in the course of mathematics, would help students to improve their skills on the one hand, and on the other would encourage the improvement of mobile learning applications.

II. SMARTPHONES

A. *Graphs and functions*

Botzer et al (2007) presented a pilot case study, where participated four female mathematics students, studying for a teaching certificate. The project was based on Math4Mobile, a cellular application for mathematics learning. This mobile learning environment includes Sketch2Go, an application which allows users to sketch graphs, increasing and decreasing functions and make visual exploration of phenomena, and Graph2Go, a graphing calculator for dynamic transformation of functions. The project included also the use of cellular video camera to record occurrences, MMS messages to exchange videos between participants and SMS to exchange verbal messages. As the researchers claimed, the contribution of the mobile environment enables the use of mathematical applications anytime and anywhere, encourage the performance of mathematical operations and enhance experiential learning [4].

Daher et al (2009) made an experiment for learning mathematics in an authentic mobile environment, which took place in an Arab middle school in Umelfahn, Israel. In this experiment participated 32 8th grade students who volunteered and owned cellular phones. Learning carried out in outdoor activities, where students could study mathematics concepts through exploration and investigation with their mobile phones. Students used algebraic midlets, from the site of Institute for Alternatives in Education (www.math4mobile.com), to see the graphs of several templates of linear functions. As the results showed, the environment of mathematics learning using mobile phones enables independent and collaborative learning in authentic real life situations, engages students in various mathematical actions and makes learning mathematics easier and faster [2].

In the same year, Daher accomplished another study to find how middle school students respond to learning mathematics with cellular phones and web applets. In this study participated 15 9th grade students. The mostly used applets by the students were Graph2Go, which enables graphs and functions drawing and Fit2Go, for linear and quadratic functions. Each one of the participants was interviewed about his or her perceptions about learning mathematics using cellular phones or applets, the differences between using cellular phones and web applets, as well all his/her attitudes about using these learning applications in the future. The participants highlighted that learning mathematics using cellular phones and applets enhances solving mathematical problems in short time, without much effort and precisely, ensures the correction of their solutions, and makes them more active in their learning [3,6].

B. The laws of arithmetic

Zhao and Okamoto (2009) from University of Electro-Communications in Japan, introduced a Mobile Mathematics Tutoring (MoMT) system for primary school students, based on individual learner's abilities. The system analyses the user's learning profile, in order to provide personalized mathematics tutoring and exercises. The system also allows discussion between students, so they can exchange ideas, experiences and questions, via email, text messaging, photos, audio recordings and videos. MoMT lays out its content using XHTML Basic, cHTML and XHTML MP. This mobile tutoring system can improve arithmetic skills and student interest in learning mathematics concepts [40].

In 2010 Diah, Ehsan and Ismail developed a promising mobile educational game for primary mathematics education." MathRush" was designed to support mathematics' learning outside of the classroom. Its framework is consisted of four parts: (1)learning theories, (2)mobile learning approach, (3)games development approach and (4)learning and education medium. The game criteria include goals, rules, competition, challenge, fantasy and entertainment. It is a fun way for children to practice basic mathematical facts such as addition, subtraction, multiplication and division. The functional areas of the prototype, such as stability, correctness and integrity of the game assets have been successfully tested on Java Wireless Toolkit Emulator platform and on Sony Ericsson K750i. MathRush is a simple but very useful game for students who just started to study mathematics [7].

Zaranis et al (2013) developed sixteen different activities for mobile teaching realistic mathematics in kindergarten education. The project was based on the principles of Realistic Mathematics Education (RME) for preschool education, which was developed in the Netherlands, targeting fundamental mathematical concepts for kindergarten students. The three levels developed during kindergarten education, aimed at counting and calculating simple additional and subtraction, calculating addition and subtraction problems, and calculating addition and subtraction using a missing variable. The applications they created used the App Inventor application development software and were tested on the Android operating system. The produced software should be user friendly to kindergarten children, without requiring reading and writing knowledge, combining animation and sound [39].

C. Algebra

Roberts et al (2011) presented the Nokia Mobile Learning for Mathematics project, in South Africa. In the 24 project, from January to June 2010, participated about 3000 10th grade mathematics learners from 30 schools across three provinces in South Africa. With the voluntary participation in this project, students and teachers had access to interactive mathematics learning materials through a mobile platform with a social media application support. Learners could work through theory sections and answer questions from a database of 10000 questions (multiple choice, true or false, spot the error, open-ended questions), categorized by topic and difficulty. Results showed that it is possible to use networking platform for teenagers' mathematics homework. However, the establishment of this kind of teaching presupposes the equal access of the students to mobile devices, in all over the country [30].

One year later, Kalloo and Mohan presented "MobileMath", a mobile learning application designed to help secondary school students improve their performance in algebra. The application, which is available on mobile phones with internet access, offers lessons, examples, tutorials, quizzes and games that support users to practice certain mathematical skills. Three evaluation studies with 57 students were carried out to examine the effectiveness of the learning application. Questionnaires, pre-tests, post-tests and interviews were used for data collection. According to the results of the analysis, most of the students enjoyed learning activities, especially games and they thought that the application helped them improve their performance in algebra [15].

D. Geometry

Wijers et al (2008) created an interesting mobile gaming and learning environment, based on geographical reality, maps and location technologies, to support 12-14 year old students. MobileMath is played on a mobile phone with a GPS receiver.The basic goal of the experiment was to help students experience mathematical concepts in the physical world. Users, playing in teams, gain points by creating virtually constructed mathematical shapes (squares, rectangles or parallelograms). The construction process was done by physically walking and clicking on the location for each vertex. To answer the research questions, they made a pilot study with 60 students in three different schools. After the game, 54 of the players completed a questionnaire. The students understood easily the goal and the rules of MobileMath. The collaboration within teams went well and there was no problem with phone using [36,37].

Kaufmann et al (2003) introduced Construct 3D, a three dimensional geometry construction tool, designed for mathematics and geometry education at high school and university. It is based on the mobile collaborative augmented reality system Studierstube, described by Schmalstieg et al in 2002. Construct 3D uses augmented reality (AR) to allow users to share a virtual space. AR allows users to see their own body and hand, as well as the results of their movements while they work. This tool offers a set of functions for construction of geometric shapes such as lines, spheres, cylinders and cones. Teachers, students, colleagues and friends who tried the system, gave feedback with comments and observations to help designers develop the application [17,18].

Tangney et al (2010), working on MobiMath, an approach to utilizing smartphones in teaching mathematics, created and presented two learning applications. "Angle

Tool” uses smartphone’s accelometer to represent the rwadout of the angle at which the phone is being held. Teaching objectives of the software are based on the geometry and trigonometry curriculum. “Cuisennaire Roots” designed to explore the addition, subtraction and equivalence of fractions. The rods consist rectangles of different colour and length which represent different fraction values. The tool enhances collaborative learning experiences, organizing groups, in which students must communicate to find the correct solutions [31].

III. TABLET PCS AND IPODS

A. Algebra

In 2006 in the University of Southern Queensland, Australia, Galligan et al examined how the tablet PC could be used in the lectures in Foundation Mathematics. Teachers in Algebra and Calculus, used tablet PCs for their lectures instead of writing on the blackboard or using a projector. As the teacher was solving a problem on the tablet PC, students could see the solution in their own tablet, send immediate answers or questions to the teacher and of course they could keep a record of the lecture. The experiment was very helpful for the students, as they could understand the lecturer easier and use the recorded lectures for revision. They also used tablet PCs for distance learning in higher education. Teachers trailed web conferences and online chat sessions via tablets for tutoring in the subjects Algebra, Calculus and Data Analysis. According to the students’ feedback, the online sessions motivated them and enhanced communication with other students [11].

Franklin et al (2008) developed a case study in a school of Southeastern Ohio, to help middle school students to learn algebraic equations, the concept of scope, absolute value and elimination. They created math videos that could be used by the students to study anywhere and anytime, using mobile devices. In this four weeks study participated 39 8th grade mathematics students, arranged in two groups: MsClass1 group contained 22 students with multiple academic levels and MsClass2 group, with 17 students included special education students and low achievers. The materials and the software used, were iMac computers, iPod touch, Microsoft Office 2003, iMovie on the Macintosh, Adobe Photoshop and iTunes 7,6.The results showed that students in both groups loved to study with iPods in group or alone and showed significant improvement in understanding algebraic concepts [9].

In 2009 O’Connell et al proposed a pen based tablet application. Algosketch is a system for fluid pen based entry and editing for mathematics with support for interactive computation. The system supports entry of basic math symbols (∞, R, e.t.c.), math relations (≤, ≥, ≠, ≈, ∩, e.t.c.), integrals, summations, roots, trigonometric, functions and matrices. Using Algosketch enables specification and computation of mathematical expressions, specification of matrices and recognition of correct input. In order to evaluate the effectiveness of the application, six subjects interacted with Algosketch via Compaq tc4400 tablet PCs which were connected to a local area connection. The evaluation of the Algosketch prototype showed that it is a promising and useful tool, which offers pen entry that is as easy as writing on paper [27].

Kiger et al (2012) examined the effect of Mobile Learning Intervention (MLI) in mathematics education of third grade students. In their nine week study participated two experiment groups at Midwestern’s Park elementary school, during the third quarter of the 2010-11 schoolyear. All school classrooms were equipped with computer, internet, mobile smartboard, iPads and iPods. According to the curricula, the learning goals of the intervention were multiplication and division facts. The comparison group, consisting of 46 students and 2 teachers, trained using usual educational techniques and the MLI group, with 41 students and 2 teachers trained using iPod touch devices, equipped with math applications such as Multiplication Genius, Mad Math, Pop Math, Flash to Pass, Math Drills, Math Magic, Flowmath and Multiplication Flashcards to Go. Due to the study’s results, on average MLI students answered more questions correctly on the post-intervention test than the comparison students [20].

Zanchi et al (2013) described in their paper the Next generation Preschool Math project (NGPM). Each unit of the project compines digital games for both individual and collaborative play and non-digital activities to support students’ learning. NGPM focus on two mathematics topics, subtizing and equipartitioning, providing rich mathematics learning opportunities for young children to understand concepts like number, quantity and ratio. The system comprises of digital and non-digital assets and a teacher’s guide. Digital Assets’ set consist eight tablet applications: Sara Skates, Birthday café, Jungle Gym, BubbleFun, Breakfast Time, Lemonade Stand, Photo Friends and ParkPlay [38].

B. Geometry

At the University of Salzburg in 2002, Markus Hohenwarter et al presented GeoGebra, a project designed to combine features of interactive geometry software and computer algebra systems. It might be used in teaching for demonstration and visualization, as a construction tool, for preparing teaching materials and a helpful tool for discovering mathematics. The system used for years a built-in a computer algebra system (CAS) for symbolic computation. They developed the symbolic features of GeoGebra 4,2 to allow students to work on fractions, equations and formulas that include undefined variables. The summer of 2013 they developed the last version, GeoGebra 4,4, which runs on iPad, Adroid tablets and Chromebooks and has been translated to more than 50 languages. In parallel they designed GeoGebraTube, a website which supports direct uploading of constructions and allows users to rate tag and comment the materials. The upcoming version of GeoGebra 5, will include a fully dynamic 3D for three dimensional geometry and graphics [13,14].

Barry Kissane (2004) presented an interactive hand held educational tablet device, the Casio ClassPad 300 [21,22]. The device includes:

- A constraint-based geometry capability (HREF1)
- A stylus for dragging and dropping expressions
- Dual windows, which allows users to select a variety of potentially windows to explore links
- A measurement bar which provides measurements of various aspects of figures that have been drawn.
- A Geometry link inside an eActivity, designed to structure and direct a user’s activity

C. Arithmetic Skills and Numerosity

Barendregt et al (2012) developed and evaluated a mathematics iPad game using multi touch interaction. The Fingu Game was designed to develop fundamental arithmetic skills, for 4 to8 year old children, focusing on conceptual subtizing, numerosity and finger gnosis. In Fingu, one or two small sets of objects are shown and the player has to count how many objects are shown and place the same number of fingers on the screen, before time runs out. There are 7 levels of difficulty in the game and if the player answers incorrectly, he loses a heart. In the three weeks pilot testing participated 11 children, 5-6 year old, from a preschool in a small city in Sweden. The more the students played the game, the more they increased the percentage of correct answers [1].

In 2003, Bull et al proposed MoreMaths, an interaction that takes place on both a desktop PC and a handheld computer. The main tutoring session of MoreMaths is on the desktop PC, where students are provided with the appropriate learning materials, which are automatically synchronized to the handheld device, that can be used anywhere and anytime [5].

Petty et al (2007) made a 6 weeks study at Glendale elementary school in Flinton, Pensylvania, to evaluate the intervention of a tablet PC mathematics software in elementary education. Three 4th grade classes with 60 students participate in the study. They used six HP 1100 tablet PCs, equipped with the Tablet Math System. This system, which was developed at Carnegie Mellon University, provides teachers with the ability to view how students attempt problems, as well as general statistics on class' performance. Tablet Math System is consisted of two complementing applications, a thin client application installed on the tablet PCs and a web application, used by teachers to assign exercises and view students' results. Teachers had difficulty integrating the system directly into their curriculum, although they claimed that the system enhanced their teaching [28].

IV. PERSONAL DIGITAL ASSISTANTS (PDAS)

Ketamo et al (2002) presented a two stages study for kindergarten's geometry teaching via mobile learning. In the first stage of the study, there were three groups of 6-year-old children: the experiment group 1, consisting 21 participants who trained with a geometry game for PC using dynamic illustrations, the experiment group 2, consisting 20 participants who trained with a geometry PC game using static illustrations and the control group with 30 children. All groups were pre and post tested for their geometry skills. On the second stage of the study, two years later, there was only one experiment group with 17 pupils, who trained on an adaptive geometry game on Compaq iPaq (PDA), connected to a server with a wireless network. According to the study's results, low skills students benefits more from the mobile learning than the averagely skilled. The PDA version of the geometry game worked extremely well, although some development has to be made [19].

Wachira et al (2009) developed a study, in which participated 20 middle school teachers, enrolled in a Midwestern university's mathematics teacher preparation course. The purpose of the study was to train the teachers on inquiry based mathematics content integrating PDAs' (Personal Digital Assistants) to teach middle school mathematics students. The content of the training was based on the National Council of Teachers of Mathematics (NCTM 2000) including data analysis, ratios, geometry and measurement. At the end of the sessions, students were given a questionnaire to express their perceptions of this new project. Most of the teachers agreed that PDA was a valuable educational technology tool and would like to learn more on how to use PDAs for instructional activities [33].

V. ONLINE APPS AND TOOLS

In recent years there have been designed and presented several online learning applications and tools for mathematics. These learning applications could be used from the students anytime and anywhere, via mobile devices using wireless connection.

Wang et al (2003) designed an open Web-based Mathematics Education (WME) system, using standard internet technologies. The WME framework allows easy and systematic development of an unlimited set of mathematics education contents and mathematics education support capabilities. The framework includes the Mathematical Education Markup Language (MeML), which provides markup elements to represent mathematics education pages, web servers to deliver pages, WME page processors to receive MeML pages and WME services including mathematics knowledge, computation, mathematics education and pedagogy services [35].

A. Algebra and problem solving

AGILMAT is a web application, designed by Tomas, Leal and Domingues in 2007 to help students learn mathematics and especially high-school algebra. It is a constraint logic programming application, which allows users to generate mathematics drills automatically, depending on the grade, the topic and the difficulty chosen and provides a one line solution for each exercise. Users can also refine exercise generation by setting different values for particular parameters [32].

In 2005 Nguyen and Kulm used web-based practice to enhance mathematics learning and achievement for middle school students in Southeast Texas. In their study participated 95 students from 6 math classes, randomly assigned to one of two treatment groups. Students in the web-based assisted learning and practice (WALA) group, did their H/W (fraction operations set and converting demicals to fractions set) in the computer labs, using Javascript, Perl and HTML files, during the 3 weeks of the experiment. They could check immediately if their answers are correct and receive adapted feedback for each answer. Participants of the traditional assisted learning and practice (TALA) group, used paper and pencil to practice on the same H/W. The web-based approach of intervention brought better results and motivated students to do their homework [26].

Edwards et al (2010) presented 4MALITY, a web-based mathematics tutoring system, designed to teach mathematical problem-solving skills and test-taking strategies for 4th grade students [8]. 4MALITY adapts to the students' levels of knowledge, by using an Artificial Intelligence decision system. The system's mathematics content is based on the Massachusetts Curriculum Framework. There are four categories of learning styles provided:

- Explain questions in terms of language used.
- Mathematical computational operation.
- Test-taking and problem solving strategies.
- Visual approaches to computation.

B. Dynamic Geometry Software

Bülent Göven and Temel Kosa examined the effect of dynamic geometry software (DSG) Cabri 3D on student mathematics teachers. This three dimensional geometry tool, launched in 2004, provides an environment in which students can explore geometric relationships and construct geometrical objects. Forty student mathematics students of Karadeniz Technical University participated in the 8 week period study. Purdue Spatial Vizualization (PSV) test, which consists of 36 questions in three sections (Development, Rotations and Views), was used as pretest and posttest for data collection. The results of the tests, before and after intervention, showed that students' spatial skills improved significantly [12].

C. Mathematical Programming

Karagiannis et al (2006) designed an online software application to facilitate the education of mathematical programming. WebNetPro is an online application for students, mathematicians and operations research scientists. It is a powerful educational tool for Linear Network Programming, which can assist the teaching process of courses such as Graph Theory, Network Optimization Algorithms and Data Structures. The tool helps users to verify their calculated solutions or convert one network representation to another. WebNetPro is implemented in the Matlab computing environment uses a graphical user interface (C.U.I.) for solving problems [16].

VI. CONCLUSIONS

The purpose of this study was to examine the most representative studies of recent years, involving online and mobile applications and tools for mathematics as well as their effect in the educational process. We presented some innovate applications which are addressed by kindergarten children to university students. These apps could be used to improve arithmetic skills, numerosity, for graphs' representation, geometrical objects constraction, algebra problem solving and mathematical programming. The results of the studies revealed that online and mobile learning applications motivated the students, making mathematics course more enjoyable and interactive than the ordinary teaching practices. The work of the developers gives promises for more learning tools in the near future, creating a new educational model.

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Submitted 28 January 2015. Published as resubmitted by the authors 18 May 2015.