Opening User Model Data for Motivation and Learning: The Case of an Adaptive Multiplication Game

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Abstract: Multiplication table fluency is of core importance, as it consists a fundamental stage of mathematics education. It is a common phenomenon that pupils face difficulties in perceiving this knowledge and achieving multiplication skills. This paper presents an adaptive multiplication game for assessing and gradually improving multiplication skills. The game also incorporates Open Learner Model elements which expose parts of the learner model to the user through easily perceivable visualizations for improving self-reflection, fostering self-regulated learning and increasing user motivation. The game has been tested with a representative sample of primary school students and based on the data collected the game and the Open Learner Model's features have been received positively.

1 INTRODUCTION

It is a common place that both elementary and secondary level of education are based on traditional methods of teaching and assessing. Downing and Haladyna (2006) claim that *"teachers teach the way they were taught and test the way they were tested"* (p. 291). Although alternative ways of assessment (e.g. portfolios, performance) have been used in curricula of other scientific domains (such as fine arts), they are not typical in the mathematics instructional procedure (Ford and Usnick, 2011). The use of non-traditional ways of assessing was strongly supported by the publication of Curriculum and Evaluation Standards for School Mathematics (National Council of Teachers of Mathematics, 2000). Specifically, multiplication table skills are considered almost a student virtue. As this knowledge is the heart of the majority of mathematical problem solving, Gagne (1983) claims that the multiplication table must be *"not just learned, not just mastered, but automatized"* (p.18). Traditionally, the dominant approach to teaching the multiplication table has been the "rote memory" or "rote learning", which is defined as a memorization technique based on repetition according to Davis (1984). However, according to Caron (2007) *"recent directions in mathematics teaching and learning toward the need for development of understanding in the uses of calculations could not support the use of rote memory alone*" (p. 279). At the same time, the related literature documents an urgent need for using alternative approaches to mathematical concepts, as rough use of drill and practise can make mathematics unpleasant and uninviting (Gersten and Chard, 1999).

This tendency towards incorporating alternative ways of teaching, practicing and assessing into traditional instructional procedures is relatively recent. There have been numerous efforts of software applications documented in the corresponding bibliography targeted at supporting the role of teachers and increasing pupil attention and participation to various lessons. Computer or electronic games are among the dominant approaches to this end.

Games in their primitive form are defined as competitive interactions based on rules to achieve specified goals that depend on skill, and often involve chance and an imaginary setting (Cruickshank and Teller, 1980). For years, playing games, even without connection to a specific educational content has been considered one of the fundamental forms of learning (Huizinga, 1949) and is therefore not surprising that games are closely linked to intrinsic educational experiences. With technology rapidly developing in graphics, sound, real-time video and audio, electronic games have become more and more entertaining and

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enjoyable for kids, as well as adults. Among all the kinds of games, educational games have one goal beyond mere entertainment, and that is education.

In this paper we combine the notion of educational games with a personalized approach and an adaptive mechanism, with the innovative idea of OLM. The intention is to support pupils in achieving multiplication table fluency in a way that motivates and engages them.

2 BACKGROUND

The integration of games in formal or informal learning scenarios has been an active field of research at a theoretical, as well as a practical level, the last decades with numerous experimental and commercial applications worldwide. The scientific bibliography of the domain is quite rich and addresses topics ranging from the use of videogames in supporting the learning process (Yee, 2006, Kirriemuir and McFarlane, 2004, Mitchell and Savill-Smith, 2004, Egenfeldt-Nielsen. 2007 Prensky, 2007), to learning theories deployed by each learning genre, case studies evaluating the effectiveness of electronic games as a teaching and learning medium (Wong et al., 2007, Smith, 2006, Blunt, 2007, Prensky, 2006), as well as the traits of certain electronic games genres and the respective educational potential they provide.

Adaptive games are games that offer an internal mechanism that stores data about each individual user and his/her interactions and is able to make inferences regarding how to adapt to the needs and preferences of this user. The idea of not only maintaining data about the user and his/her interactions but also exposing some of them in an adequate form, is a step beyond adaptive educational gaming that leads to Open Learner Modeling. Open Learner Modeling was introduced as a notion in the domain of intelligent tutoring systems and adaptive learning environments for supporting personalized instruction to learners. Traditionally, learners were not given any access to the data maintained about them by the system in the respective learner model. After realizing though the educational value and benefits learner model data could offer if they were exposed to learners and instructors, this approach gradually changed (Self, 1990). More specifically, giving students access to view some of their model's aspects may improve self-reflection, foster self-regulated learning, provide better personalization transparency and increase user motivation (Bull and Kay, 2007), (Hsiao et al., 2010), (Mitrovic and Martin, 2007). Since then, various information visualization techniques have been extensively deployed in Open Learner Models (OLMs) to represent in an easily perceivable way learning data ranging from knowledge and skill levels, to difficulties, misconceptions and other dimensions of current learner status and recorded activity (Law et al., 2017).

OLMs are learner models that can be viewed or accessed in some way by the learner, or by other stakeholders of the learning process (e.g. teachers, peers, parents). Thus, in addition to the typical purpose of a learner model (i.e. maintaining data to enable adaptation according to individual current learning needs), an OLM can also be of direct use by the learner (Bull and Kay, 2010). In principle, any type of learner model can be accessible to users, and the method of presenting the learner model may depend on the purpose of opening it, the target users, the learning context and the learning tasks to be performed (Bull and Kay, 2016). In addition, soon after the introduction of the OLM concept, researchers proposed the idea of Social OLMs (OSLMs or OSSMs) (Bull and Kay, 2007; Bull et al., 2007). OSLMs are defined as OLMs that integrate a social dimension and thus *"…enhance their cognitive aspects with social aspects by allowing students to explore each other's models or an aggregated model of the class and also provide guidance to appropriate content topics"* (Brusilovsky et al., 2016).

Visualization plays a central role in presenting the adequate model contents to the intended users in an easily perceivable way. As argued by Bull and Kay (2016), learner model data simplification through visual presentation is necessary, since in most cases the internal learner model mechanisms and inference logic is too complex to display to learners, teachers, or parents.

OLMs can be visualized in various ways to address the many usages and potential users that access those models (Bull et al., 2010). Typically, OLMs use fill, color, position or size to visually represent level of understanding, degree of competencies and acquired skills (Bull et al., 2016). The most widely used types of visualizations comprise bar charts, pie charts, radar plots, scatterplots, tables, timelines, network diagrams, skill meters, etc. (Leonardou et al., 2019). Systems offering OLM features may support multiple representations and research has shown that even though some visualizations appear to be preferable overall, there are users that often choose to use more than one and prefer to change representations over time (Xu and Bull, 2010, Mabbott and Bull, 2006, Johnson and Bull, 2009). In the case of OSLMs, visualizations may also include (apart from data about the specific learner) data that allow comparison of the current learner with individual peers, or a group of learners (e.g. the best learner of the 'class', other individual learner(s), or the average 'class' performance).

Apart from whether an OLM visualization incorporate elements from other learners' models, it can also be classified on the basis of its internal structuring level, as highly-structured, medium-structured and unstructured. This classification regards whether the representation projects the learner model on a visual view of the learning content concepts and their relations (i.e. whether the domain is represented within the visualization) (Bull et al., 2016).

3 RELATED WORK

The developed educational tool deals with multiplication tables. There are many sites that share the same educational theme. Some indicative examples can be found at https://www.timestables.com/games, https://www.multiplication.com, https://www.topmarks.co.uk/maths-games/7-11-years/times-tables,https://www.mathsisfun.com/timestable.html, https://www.free-training-tutorial.com/times-tables-games.html, https://www.helpingwithmath.com/resources/games/target_2x/2xtable.html. All these games use bright colors, impressive graphics, movements and sound effects to captivate user's attention and to offer extra motivation for the pupil to use them but none of them maintains user model data nor do they support OLMs.

On the other hand, there are many efforts documented for incorporating OLMs in the instructive procedure of mathematics apart from multiplication tables. One such characteristic example is a tool on solving linear equations aiming at 7th graders (Long and Aleven, 2013). Bull and McKay (2004) presented Subtraction Master, a learning environment with an OLM for two and three-digit subtraction, which addresses schoolchildren. Another tool is the "*Point of View*" (Bull et al., 2010), which was designed for 10 to 11-year-olds and involves learning science subjects (Earth, Sun, Moon; Health & Teeth; Food Chains & Life Cycles).

Fraction Helper (Lee and Bull, 2008), is a learning environment with an OLM aimed at helping children to identify their problems with fractions and their parents support them to overcome any misconceptions.

CALMsystem (Kerly and Bull, 2008) opens the learner model to students, allowing them to see the representations of their current knowledge level as assessed by the system, and their self-assessment for each of the topics in the subject domain. The CALMsystem environment is browser based, operating independently of an ITS, and allows easy access to users from a variety of platforms.

NEXT-TELL offers two example tools for primary level math training targeted at school pupils. First, a web-based multiplication trainer named 1×1 Ninja (http://next-tell.eu/portfolios/primary-level-math-training/) for tablets or smart phones. Teachers can retrieve a detailed summary of the competency level of pupils. Based on the visualizations, they can easily identify the low performers and, more importantly, which competencies are lacking. Secondly, Sonic Divider (http://next-tell.eu/portfolios/sonicdivider/) is a tool designed for practicing divisions both the classroom and as homework. It supports practicing the formal sequence of written divisions using a gamified approach. Pupils receive competence-based feedback and they can collect points, as well as compare their scores later. Teachers can quickly access an overview about the achievements, scores, and competency levels of their pupils.

4 RESEARCH IDEA AND RESULTS

The proposed approach is based on combining an adaptive educational game on the multiplication table (Leonardou and Rigou, 2016) with OLM elements. The game incorporates adaptive behaviour, addresses primary school pupils of 2nd to 4th grade, concerns self-assessing multiplication table skills and gradually improving them. More specifically, the tool aims to discover each pupil's weaknesses and by focusing on them, to help overcoming them. The structure of the game includes 3 levels of increasing difficulty, where information collected from level 1 is used as feedback in level 2, and information from the level 2 is the input for constructing level 3. In the initial game version, the user could choose from 4 family numbers, an approach based on the idea of Griffon (2005), where it is important to support learners build networks from new to known knowledge by building on and consolidating new knowledge in a natural development and with extensive practice. The game adaptation mechanism used data about user performance collected during the current session, without requiring setting up a personal account. This was a limitation of the first

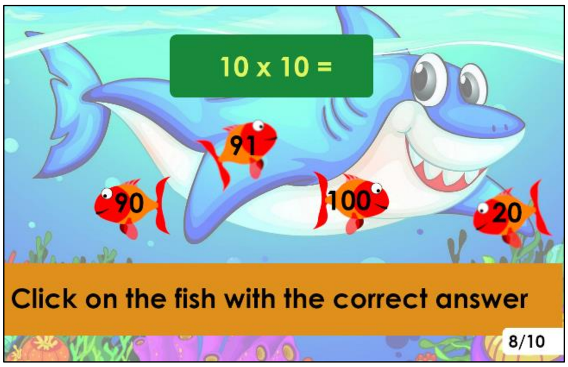

Figure 1: Level 1 indicative screenshot.

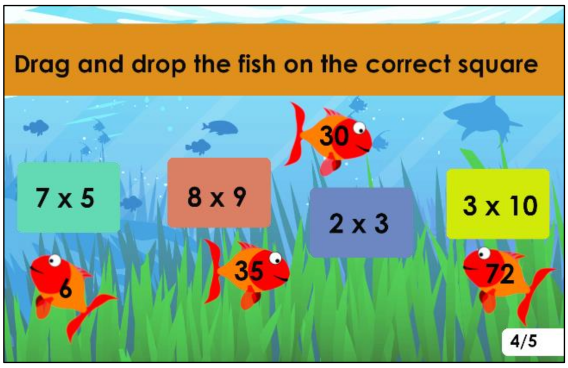

Figure 2: Level 2 indicative screenshot.

game version as it was not possible to monitor pupil gradual progress and learning.

In the new version, the underlying user model maintains detailed information about pupils and their progress during repetitive sessions and access to the game is provided through personal accounts. The database stores demographic and user account data, information on each session concerning selected multiplication table numbers to practise, number of correct and wrong answers, as well as date and time information.

This application based on Caron (2007) belief that *"practice over many times is all that is needed"* (p.281), maintains the structure of the previously developed multiplication game and consists also of 3 levels. In the first, a set of multiplications is given, each followed by 4 potential answers to choose from (multiple-choice). In the second level, each question comprises 4 multiplications and 4 answers and players are asked to match each multiplication to its correct answer by dragging-and-dropping answers on frames with multiplication questions. In the last level the player has to answer multiplications of a specific number's table, using the game onscreen keyboard to enter the answer. Upon completing each level, pupils are given the option either to move on to the next level or see their accomplishments in the level they just finished by accessing data of his learner model. After completing the last level, they can also see their overall progress in the current session.

From an implementation point of view, the game was developed in Corona SDK (https://coronalabs.com), a cross-platform framework that empowers developers to create 2D games and mobile applications for iOS, Android and Kindle, desktop applications for Windows and OS X, and connected TV applications for Apple TV and Android TV. It uses integrated Lua layered on top of C++/OpenGL to build graphic applications. Lua (https://www.lua.org) is a lightweight programming language designed primarily for embedded systems and clients. Lua is cross-platform since it is written in ANSI C, and has a relatively simple C API. For building the database, SQLite (https://www.sqlite.org/about.html) was used an in-process library that implements a self-contained, serverless, zero-configuration, transactional SQL database engine.

4.1 Gameplay

Overall, and since the game addresses schoolchildren, it is important to visually captivate their interest so that they are willing to use it. Therefore, pleasant graphics, bright colours, related sound effects and animation have been deployed.

Initially an introductory welcome message appears, while the player fills in a textbox with a nickname to be used as identification and to associate all recorded activity with. In the following screen the player can select the number(s) of the multiplication matrix to practice on. For extra support apart from individual numbers, 4 number families are offered according to the methodology of teaching multiplication in the Greek formal public education. The amount of multiplication questions is level 1 and level 2 differs depending on the amount of the selected numbers. Level 1 (Figure 1) randomly selects multiple-choice questions from the group of the selected numbers and the player has to click on the fish-object marked with the correct answer/value. If the given multiplication is answered correctly, a reward message appears and the complete multiplication, for educational reasons. If the answer is wrong the player can try again (the wrongly pressed object disappears), until the correct answer is provided.

The game is supported by an underlying adaptive mechanism. According to this mechanism and among the selected numbers, a 'weak' number is detected based on an algorithm that compares the percentage of the wrong answered questions, the percentage of the right answered questions and the amount of the given questions for each number. This mechanism is activated upon completion of levels 1 and 2, and the 'weak' number is passed on to level 2 and 3 correspondingly, so that the system adapts the selection of next questions to this identified weakness to provide the player with more relevant multiplication questions and thus improve skills on this number.

Upon completion of level 1, a screen with two choices is given: the player can press one button to continue to the next level or can see his/her progress by accessing data stored in the respective user model. If a choice is made to see the learner's progress, a screen appears projecting visually and textually the score in each tested number by calculating the success percentage (amount of right answered questions/ amount of total given multiplication for this number). Specifically, a percentage less than 50% is assessed as "not good" and is accompanied by a non-smiling face, a percentage between 50% and 65% is assessed as "good" and is accompanied by a smiley face, whereas a percentage between 65% and 85% is assessed as "very good" and a happy face appears. Finally, for percentage more than 85% is assessed as "great" and a very happy face with thumps up appears. The choice of smiley faces for skill assessment visualization was made since a smiley face representation belongs to simple quantised representation category, which is considered ideal for schoolkids. Smiley face representation with scalar variations depicts the level of knowledge or contrast the current learner level with the level of peers. For example, in Subtraction Master (Bull and McKay, 2004) the child views a series of simple smiley faces representing the extent of their subtraction skills at different levels of difficulty.

In level 2 (Figure 2) the player is presented with a set of four multiplications in rectangular frames and four results written on fishes and is asked to assign them correctly so that each fish is dragged and placed in the 'cave' that corresponds to its number. In the case of some wrong assignment the fish is returned to the center and the player can try again (all fish that were placed correctly disappear). Completing this level, the player has also the choice to move on to level 3 or to see detailed score information before doing so (Figure 3).

In level 3 (Figure 4), the player faces exclusively the multiplication table of the number that the previous level identified as the weakness. As this level is the last one, its difficulty is higher. Multiplications are given in sequence and the player

Figure 3: Progress screen.

needs to provide the answer with no help provided. In case of a false answer, no second chance is given, but the player is informed about the right answer. In this level visually, the player helps the fish reach the higher level of the rocks and avoid the shark. A right answer moves the fish one position up, while a wrong answer makes the fish slip to a lower position. The level ends successfully if the upper point is reached or ends unsuccessfully if the player uses the number of allowed tries without reaching the target. At the end of the game session the player can see level 3 scoring and overall game accomplishment.

5 CRITICAL ANALYSIS

The developed multiplication game was tested with 36 pupils (17 girls and 19 boys) of the primary school. All pupils had prior experience with computer games but only 5 of them had played educational computer games in the past. Regarding ICT fluency, pupils were experienced with web browsing and smartphones apart from the typical ICT course they are taught in school. The evaluation sessions took place during the school year, while students are much more active and 'alert'. During each pupil session in the game the database is filled with detailed information about pupil activity and progress. Pupils answered a questionnaire (a revised version of Brusilovsky et al., 2016) about usability and usefulness of the multiplication game and the OLM elements available. Moreover, questions also focused on the motivational value of the provided OLM visualization. Table 1 presents the questions with the average and standard deviation of the collected answers. Values range from 1 (strongly disagree) to 5 (strongly agree).

Table 1: Subjective evaluation questions.

	Questions	AVG	SD
Q1	I enjoyed playing the Multiplication Game (MG)	4.78	0.42
Q2	I liked the interface of the MG.	4.58	0.76
Q3	The given instructions were enough to understand how to play the MG.	4.28	1.33
Q4	I found it useful to see my progress in MG.	4.17	0.99
Q5	Seeing my progress in MG made me realize how well I know the multiplication table.	4.53	0.99
Q6	Seeing my progress in MG motivated me to plan for specific homework.	3.92	1.16
Q7	It was useful to see my progress in each level/different type of questions.	4.28	0.96
Q8	I find the used visualization (smiley faces) a good idea.	4.75	0.55
Q9	I believe MG is more a game than a lesson.	3.81	1.45
Q10	I believe MG is more a lesson than a game.	2.83	1.59
Q11	I would like to play MG at my home PC, as well.	4.5	0.9
Q12	I would like to see the scores of my peers.	4.17	1.28
Q13	I would like to see the class average score.	4.11	1.22
Q14	I believe that seeing the progress of others would motivate me to work harder.	4.11	1.02
Q15	It is important for me to see my rank among my peers.	3.94	1.41

All participants enjoyed playing the game (q1), 89% enjoyed the application's interface (q2) and 81% felt that there is no need for extra instruction on how to play the game (q3). 78% found useful the opening of the model for seeing their progress (q4), 89% believe that opening the model supports self-reflection (q5) and 67% believe that opening the learner model is a factor of self-motivation (q6). 75% considered it significant to see their progress after completing each level and thus watching their progress in different types of questions (q7), 94% agreed with the usage of smiley faces as the type of visualization provided (q8) and 64% felt that the application has more of an entertaining than an educational role (q9), whereas 47% didn't agree with the opinion of a more educational than entertaining role (q10). 83% would like to have the opportunity to play again the game at home (q11), which gives an extra support of the assumption that pupils enjoyed interacting with the tool. 78% were interested in the idea of social OLM (q12). This finding is interesting as providing access to score of others seems motivating to competing pupils. 69% would like to see the average progress of their classroom (q13). 72% believed that OSLM would offer self-motivation (q14), thus the ability of seeing peers progress will contribute in self-directing their study. 69% would like to see their rank among their classmates (q15) and thus to contrast their level of efficiency with all classmates.

Questionnaire responses suggested that pupils had positive reactions towards the OLM approach, as well as the idea of OSLM. They consider it easy and pleasant to interact with and didn't underestimated the educational role it plays.

Many of the game testers after completing specific levels chose not to see their progress: only 38% choose to see Level 1 progress, 44% Level 2 progress and 38% Level 3 progress. On the other hand, the vast majority (88%) chose to see the total progress of the activity at the end of the game. When asked, pupils stated that they preferred to keep on playing because they were amused by the process and wanted to see their overall score at the end, an approach that is considered logical for their age group and the purpose of the application. In addition, this is also supported by the answers received on the q7 where pupils considered the application a game rather than an educational activity.

6 CONCLUSIONS

This paper presented the design and implementation of an adaptive educational game addressing primary school students for practicing and mastering multiplication table skills. The game incorporates OLM characteristics as it maintains in a properly structured database information about the pupils and their activity and progress. Based on the data collected during the testing sessions, there is strong indication that both the ideas of OLM and OSLM were perceived positively. It was observed that participants enjoyed playing and faced no difficulty in understanding the way the game works.

Regarding future plans for extending this work, the application is going to be expanded with social OLM elements, as it will open not only to the user himself but also to peers and teachers. In the new version currently under development, users will be able to access specific anonymous information of peers and watch a summative view of the class progress, whereas the teacher will be able to access detailed pupil data.

In the current version for each selected number, the system maintains the sum of multiplications given, the sum of the right answered multiplication and the number of wrong answered multiplications. An idea for improving the application is to maintain a 2-dimension table with the specific wrong answered multiplication combination so that the teacher can reach safer pupil assessment decisions and the system can better match each pupil practise needs.

One of the limitations of the current analysis is restricted number of test participants when considering the number of pupils per grade as well as the narrow time frame. It has been planned to examine the effectiveness of this tool in real classroom conditions during the school year with more pupils per grade, so as progress would be more thoroughly recorded and safer results could be reached. The pupils are expected to use the application in school using the computer laboratory class, either with the presence of the teacher, who will guide them on the numbers to be selected for the practise (according to the stage of the instruction procedure and progress), or either as part of the computer lesson, where the pupils will be able to play the game in an unsupervised mode.

Among the experimental ideas is to check the application in two versions, that is with and without the OLM elements, as we believe that this comparison will provide interesting results. Such experiments will allow for the comparative analysis of OLM and non-OLM game versions on the basis of learning outcome as well as student preference, metacognition and motivation.

Another idea expanding the game features is to give pupils the option to become more active (Himmele and Himmele, 2011) by tailoring the game interface elements (such as the background image, the image objects, and the kind of visualizations) according to their preferences.

The last direction in our plans is to introduce to the game a stronger instructional parameter in the form of graphical explanatory feedback that will help pupils understand calculations that explain answers they failed to calculate correctly (Harries and Barmby, 2007).

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