Learning Polynomial Operations: A Game Based on Students' Preferences

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Abstract: In this paper we describe a pedagogical interactive activity currently in development, which takes the form of a mobile game. The subject of the game is a curriculum topic in Mathematics, namely the four elementary operations on polynomials. The design options considered emerged from previous work of the authors, specifically a survey on the gaming preferences of students and their favorite game. We present the main results of our research and how it has contributed to the creation of the game.

Introduction

Mathematics is a course that presents students with several challenges, and the students often show little interest and engagement with it. Therefore, the students' results are, in many cases, disappointing. On the other hand, videogames are very appealing to students, and they spend a great deal of time playing them. If part of that time is used to bring students closer to Mathematics learning, their engagement will be hopefully greater, and learning should be improved.

Several studies have shown that mobile learning presents many benefits, such as ubiquity, convenience, localization, personalization, and learner-centered education (Berge, & Muilenberg, 2013, Crompton, 2013, Parsons, 2007). Similarly, Traxler (2007) points out that mobile learning is characterized by being "just in-time, just enough, and just-for-me" (p. 5). Other studies (Carroll et al., 2002, Naismith et al., 2004, Attewell, 2005, 2008) also refer to several pedagogical advantages in the use of mobile phones. On the one hand, mobile phones provide the students with greater autonomy and control over their own learning, by allowing them to easily access the necessary contents when and where they need it. On the other hand, mobile phones contribute to more motivation and greater participation in the learning activities. Mobile phones also allow more interactions between the participants online, due to the proliferation of apps, social networks and mobile-friendly open access resources (Kukulska-Hulme, 2014). Mobile learning through games also has several benefits, related to evaluation, flexibility, student performance, motivation, well-being and support for the individual needs of the students (McFarlane et al., 2002, Gee, 2003, 2008, Gros, 2002, Klopfer, 2008, Molenet, 2010, Prensky, 2001, 2010, Squire, 2011).

This paper is organized as follows. First we briefly describe the survey applied to the students and the rationale behind it. We then outline the main results obtained from this survey. In the following section we illustrate the design of the game created, highlighting the options we made and relating them to the results obtained in the survey.

The survey

We developed a survey with the purpose of identifying the games that the students of the 3rd cycle of basic education (K7 to K9) prefer on mobile devices and the characteristics that they value in these games.

The design of the survey was based on the Technology Acceptance Model (Davis, 1989). This model, usually denoted by TAM, is an adaptation of the Theory of Reasoned Action (Fishbein & Ajzen, 1975), that claims that the actions of an individual emerges from his beliefs about the consequences of his behavior. In the particular case of a decision on the use of a new technology, Davis proposes that the key beliefs guiding that decision are the *perceived usefulness* and the *perceived ease of use* (Fig. 1). The first is related to the belief that the new technology will improve user performance and the latter is related to the belief that the use of the new technology will require no effort.

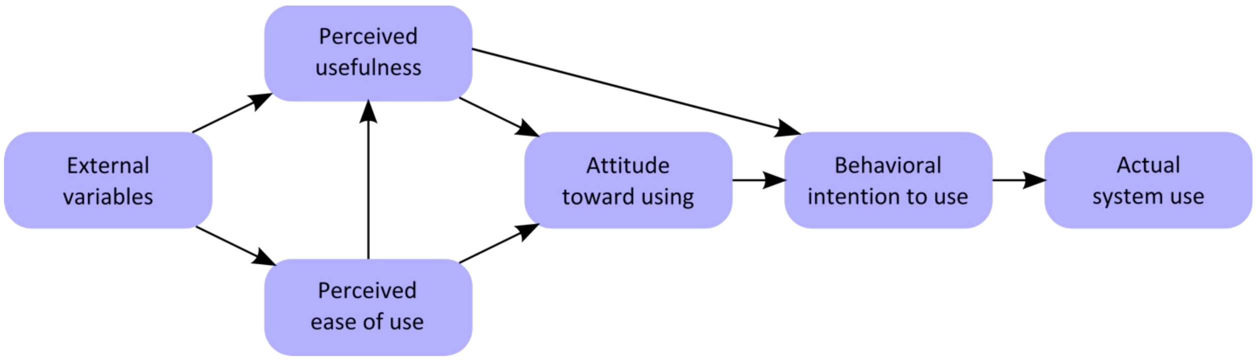

Figure 1: The Technology Acceptance Model (Davis, 1989)

The purpose of our survey was to identify the preferences of use of a specific technology, namely mobile games, where the usefulness is not of the same nature as other technologies. Usefulness, in this case, can not be defined as an improvement of user performance, as in TAM, but as an entertainment capability. Due to this characteristic, several authors (Moon & Kim, 2001, Liang & Yeh, 2008, Yang & Hub, 2012) have proposed substituting the construct "perceived usefulness" with "perceived playfulness". This construct is related to flow state (Csikszentmihalyi, 1992), which happens when the player is deeply engaged in the game. Yang & Hub (2012) have concluded that social factors, as the feeling of belonging to a virtual community, also have influence on the use intent.

Regarding the construct "Ease of use" of the TAM model, the students were questioned about the perceived difficulty of the game using a Likert scale, whether that difficulty can be changed and whether it changes throughout the game. This analysis is important, because frequently the ease of use varies during the game, and complex situations often require knowledge obtained in easier phases of the game. As Gee (2008) puts it: "Such encouragement works through in-game features like the increasing degrees of difficulty that a player faces as the levels of a game advance or when facing a boss that requires rethinking what one has already learned" (p.46).

To analyse the construct "Perceived playfulness", we asked what the students liked most and least in the game, through an open-ended response. We also asked for an evaluation of different parameters relative to their most played game, using a Likert scale. These parameters are related to the characteristics of the digital generation (Prensky 2001, Gros 2002), such as speed, cooperation with other players, non-linearity and decision making, or the importance of fantasy and immediate rewards. These parameters also analyse the importance of social factors.

The survey intended to characterize the gaming habits of the students, their gaming preferences and the reasons for that preference. The survey was applied to 298 students of a school, 154 males and 144 females, mostly between the ages of 12 and 14, who answered the questionnaire online. The games most played by the students were different according to the platform used. The results obtained are detailed in (Tab. 1). The study showed that the difficulty of the most played game is correlated with the number of hours played per week and playing alone or with friends. The students that play harder games play more hours per week and with friends.

These favourite games were studied to understand in which way the learning principles of Gee (2003) were present in them. This study was the basis for many of the options taken in the design of the game we propose, as described in the next section.

The results of the survey on the characteristics of the favourite games also gave useful information regarding some design options. The characteristics that the students declared to be most present in these games are indicated in (Fig. 2).

Device	Laptop	Mobile phone	Handheld console	Tablet	Smartphone
Most played games	The Sims	Grand Theft Auto	FIFA	Bad Piggies	Hill Climb Racing
	Minecraft	Puzzle Bobble	Pro Evolution Soccer	FIFA	Grand Theft Auto
	Pro Evolution Soccer	Bounce Tales	Grand Theft Auto	Stardolls	Jetpack Joyride
	Grand Theft Auto	Where's My Water	Call of Duty	Subway Surfers	Fastball
	Crossfire	Crazy Penguin Catapult	Little Big Planet	Jetpack Joyride	Fruit Ninja

Table 1: The games most played by K7 to K9 students

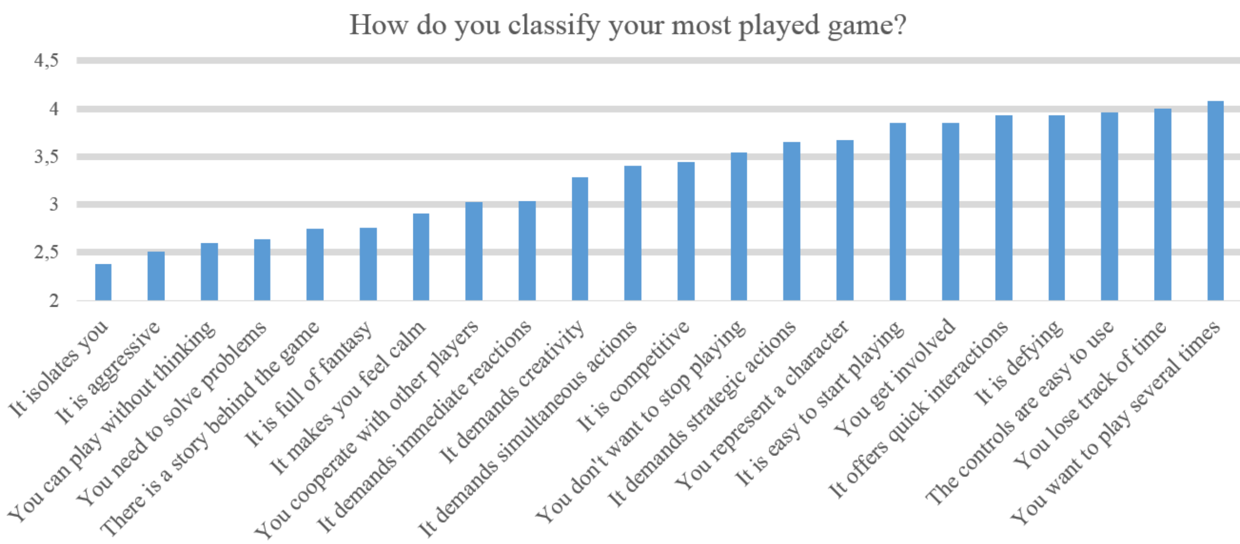

Figure 2: The classification of the games most played by the students

From this study we concluded that the games most played by the students are characterized by inducing a flow state according to Csikszentmihalyi (1992), being easy to play and demanding quick interactions. We refer to Barros & Carvalho (2013) for a more detailed analysis of the results of this study. These aspects were considered in the development of a pedagogical activity, which we describe next.

The pedagogical interactive activity: a game for mobile devices

Based on the preferences that emerged from this survey, and the learning principles embedded in the electronic games (Gee, 2003), we created a pedagogical activity, within the field of mathematical learning, in the form of a game for mobile devices.

The game is targeted at students of the 3rd cycle of basic and secondary education, that is, from the 9th to the 12th grade. It is a puzzle game, where the player has to solve several problems, of increasing difficulty. The gaming genre was selected among several possibilities, since we wanted the students to develop their mathematical reasoning and their problem solving capabilities. However, some levels have very quick solutions, mainly those at the beginning of the game, since the students in the survey have shown preference towards games with quick interactions.

The chosen operating system was Android, which is the most used by students. The game is controlled by touch, in any smartphone or tablet with this operating system, thereby respecting the preference of the students by games with easy interactions. In each level, the polynomials presented in the game must be manipulated, in the literal meaning of the word, by using the four elementary operations (adding, subtracting, multiplying and dividing), to try to obtain a predetermined result presented in the game (Fig.3).

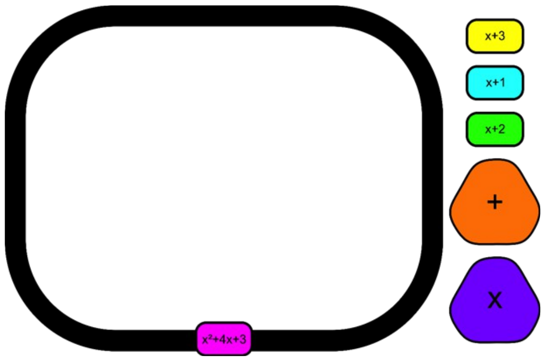

Figure 3: The position of the pieces at the beginning of a level

The game begins with a tutorial, consisting of the first level of the game. In these initial levels, the game mechanics and the meaning of various objects are explained. This was implemented bearing in mind the Subset Principle (Gee, 2003), that stipulates that learning begins in a simplified subset of the game, not apart from it. We also considered the Incremental Principle, which is related to the way in which the initial levels of a game create the basis for the resolution of more complex situations in later stages of the game. The game does not explain formally how to perform the various mathematical operations involved, but the simple cases presented at the beginning allow the player to understand how these operations are performed. This design option is based on the Material Intelligence Principle (Gee, 2003), which states that the game objects store knowledge that can be used by the players, combined with their own knowledge, to obtain more complex results.

The game consists of several levels of increasing difficulty. It is thus intended that the game meets the Regime of Competence Principle (Gee, 2003), which states that players should feel the game as challenging but not impossible. At each level, the goal is to build a certain polynomial, which is shown at the bottom of an assembly area. For that purpose, the player is provided with some polynomials, each in a draggable box, and some draggable operation symbols that allow the player to manipulate these polynomials. The player has to drag the boxes and the operation symbols, combining them appropriately to achieve the goal. The boxes are dragged into the assembly area with the finger and the links between the various boxes are also formed with the finger. In the situation depicted in (Fig. 3), the player should conclude, after observing what is provided, that the solution is obtained through the equation $x^2 + 4x + 3 = (x + 1)(x + 3)$ and the boxes should be positioned as in (Fig. 4).

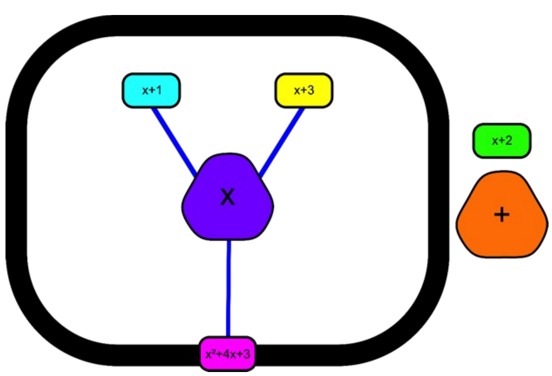

Figure 4: The position of the pieces after being manipulated

The game allows the player to present any one of the possible solutions, which in this case are only two, namely $x^2 + 4x + 3 = (x + 1)(x + 3)$ and $x^2 + 4x + 3 = (x + 3)(x + 1)$. In more complex situations there may be a wider range of possible solutions, in the spirit of the Principle of Multiple Paths (Gee, 2003), which allows the player to explore various alternatives and progress in the game in different ways.

Having completed the assembly, the game verifies if the player has reached a correct solution, by performing the various computations explicitly. To this end, the boxes move along the paths that the player has created and are transformed by the operation symbols that the player has placed, as in (Fig. 5).

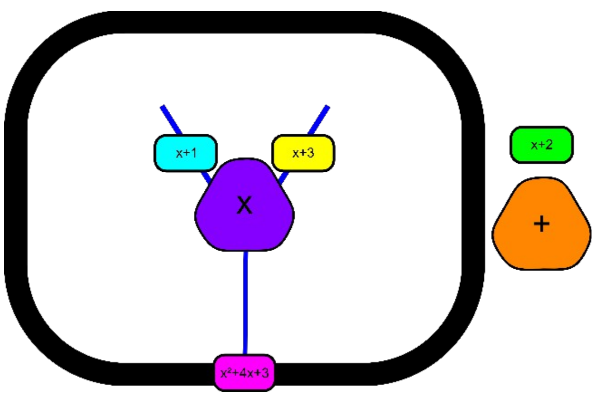

Figure 5: The explicit calculations performed by the operation symbols

These transformations illustrate the Material Intelligence Principle mentioned above, and the Multimodal Principle (Gee, 2003), since the calculations are not shown to students in a textbook, as is usual, but through a dynamic process and multimedia elements. The game also follows the Amplification of Input Principle (Gee, 2003), since with only a small movement of the pieces, several quite complex calculations are made.

If the player has found a solution to the problem presented, the next level is unlocked. Otherwise, the player will have to combine the boxes in different ways, until a solution is found. There are no penalties for presenting a wrong "solution", nor can the player "lose" in a given level, that is, the player does not have to start the game all over again, repeating the simpler levels he has already mastered. This option is based on four principles of learning outlined by Gee: the Psychosocial Moratorium Principle, which states that players can take risks without fear of consequences in the real world; the Practice Principle, which is related to the great amount of time spent by the player practicing; the Probing Principle, which defends that the player should repeat the cycle of placing, testing, accept or refute hypotheses to solve the problem; and the Intuitive Knowledge Principle, which values not only explicit knowledge but also conscious and intuitive knowledge, obtained through experience in the game.

The game has a rewarding system that consists of granting medals to reward the experience and skill of the player. Some examples of medals are: "You have solved 10 problems", "You have solved 4 problems in a row without mistakes", "You have solved a division problem in less than 30 seconds". The game levels are presented in an increasing scale, which allows the player to see where he stands at each moment. By this, we intend to fulfill the Achievement Principle, which proposes to acknowledge the player's achievements through rewards, awarded from the beginning of the game, and adapt it to each stage of the game. Beyond the individual game mode, the game has also a creative mode. This game mode allows the construction of new levels, through the choice of the objective and the operation symbols and polynomials available in that level. These levels can then be presented to other players, as a challenge. This mode seeks to implement the Insider Principle (Gee, 2003), which argues that the player should not just be a consumer of the game, but also a teacher and producer.

Conclusion

In this paper we have described a pedagogical activity that we created having in mind the results obtained from a survey on the gaming preferences of students. This activity is being created as a mobile game, and at the time of the submission of the paper it is still at the earliest stages of development. We plan to have a working prototype by the time of the conference. The design options that were made, were based on the preferences of the students on their gaming habits, and on the learning principles of good videogames, proposed by Gee (2003). When the game is ready to use, it will be presented to the students and we will conduct a study to see in what way the game promotes the learning of the four basic operations on polynomials.

We hope that these choices may contribute to the motivation of the students in the learning of this topic of Mathematics and that the students become more proficient in factoring and operating with polynomials and develop a better understanding of the binomial expansions.

Acknowledgments

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