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Improving arithmetic skills through gameplay: Assessment of the effectiveness of an educational game in terms of cognitive and affective learning outcomes

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ABSTRACT

The present study assesses the effectiveness of a commercial educational math game for improving the arithmetic skills of children. Eighty-eight second graders were randomly assigned to one of three groups: a 'gaming group' which was instructed to play through the entire commercial game 'Monkey Tales', a group which was instructed to complete math exercises on paper and a control group that that did not receive any arithmetic exercises. We used a multidimensional approach to estimate the impact of game playing on objective measures of arithmetic performance such as speed and accuracy on a math test, as well as subjective measures such as math anxiety, enjoyment and perceived competence. Overall, the present study shows that the use of games for arithmetic can be beneficial both in terms of affective and cognitive learning outcomes.

1. Introduction

Playing digital games has become a popular pastime amongst children. According to the Federation of American Scientists, children aged 8–18 spend on average 50 min per day playing digital games [20]. In Europe, the statistics of digital games use show a similar trend. According to the EU Kids Online network, 9–16 year old internet users spend 88 min per day online and, when children start using the internet, playing games is reported as the second most common activity after finishing schoolwork [14].

As digital games increase in popularity, game developers realized the potential of capitalizing on their entertainment value by offering instructional content during game play [22]. This has given rise to the genre of "serious games" that employ the medium's rich, role-playing, story-based environments to teach, train, and change knowledge, attitudes, and behavior [7]. While serious games have been used in a broad range of domains, e.g. military, government, education, corporate, healthcare, the present study focuses on the use of math games in education.

1.1. Math games in education

The idea of using games to help children learn math is not new. According to Van Eck and Dempsey [26], in 1985 a large study was conducted by the National Council of Teachers of Mathematics (NCTM, United States), who tested eleven math

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games for different grades with 1637 participants. The authors concluded that instructional games could be effective for higher grades when designed according to the curriculum and implemented with instructional activities.

To the best of our knowledge, the study conducted by the National Council of Teachers of Mathematics is the only study in which games for all grade levels were systematically tested. Most of the other studies reported in the literature focus on games that have been developed for a particular age group. Recently, it has been shown that very young children can also benefit from the use of math games. In a recent study, an internet game was used in conjunction with other classroom activities to teach probability and statistics to 4- and 5-year-old children. The children who played the game showed improvement in their understanding of probability [18]. Likewise, a recent study conducted with second graders (7–8 years old) showed that the use of a handheld game (Skills Arena [13]) was beneficial to students learning mathematics, in particular for low-ability students, regardless of gender and ethnic background [21]. The results demonstrated that pupils who played the game outperformed pupils who did not on a mathematics test. Likewise, the scores that the students obtained in the game correlated significantly with achievement scores on the mathematics test. Additionally, in a recent experimental study assigning 10 high school algebra and geometry classrooms to either a treatment or a control group has shown that students who played a math game (Dimension M [4]) improved significantly in mathematics performance compared to their non-gaming peers, but there were no significant improvements found in their motivation. Prior mathematics knowledge, computer skills, and English skills did not contribute to the students' motivation or mathematics performance [10]. Similar results suggesting that playing games can lead to gains in accuracy and calculation speed and improvement in attitude towards math in 10 to 11 years-olds, have also been reported [16]. All the studies cited above suggest that children benefit from playing games as compared to those who do not.

One crucial issue that has rarely been investigated is how using a game differs from using traditional methods. In other words, to what extent does a gaming environment add value to math education, over and above the learning effects of traditional methods? Without a control condition involving classical training methods, it cannot be ruled out that the beneficial effects of playing an educational math game are not bound to the gaming environment but merely to the exposure to mathematical content. To our knowledge, only two studies have touched upon this issue. Koran and McLaughlin [11] compared the effectiveness of drill and a mathematics game in teaching basic multiplication to 5th graders randomly assigned to 2 groups. After a baseline phase of 6 instructional days, each group received either a math game activity or drill for 10 instructional days. The results showed that both activities were equally effective in teaching multiplications and improving math grades. However, between the two groups, the children who played the game reported more enjoyment than the children who used traditional methods. Similarly, an empirical study in which the outcomes of playing a math game vs. paper-and-pencil math exercises were tested, showed that 4th and 5th grade elementary school pupils developed more positive attitudes toward mathematics after five weeks of playing a computer math game (Astra Eagle [25]), but that there was no significant effect of computer gaming on students' cognitive test performance compared with paper and pencil drills [9]. While these studies provided some indications as to the effectiveness of using math games for older children, several questions remain regarding their effectiveness for younger children and the actual learning gains compared to paper exercises and no assignment. The objective in the current study is to assess the cognitive and affective learning outcomes of playing a commercial math game compared to paper math exercises and no assignment over the course of three weeks.

1.2. Assessment of the effectiveness of math games in education

As pointed out by de Freitas [3], the field of serious games needs more rigorous baseline studies that map the different uses of serious games and quantify their effectiveness. While there is currently a lack of consensus about how the effectiveness of serious games should be assessed, a general practice in the field is to consider not only the educational but also the motivational impact of games, as both cognitive and affective factors are known to interact in many aspects of daily life. According to McFarlane et al. [15] there are three areas in which the use of digital games can be effective in education: to train general cognitive abilities and skills, to evoke positive affective reactions and thus stimulate motivation, and for knowledge- and content-related learning. Consistent with this idea, the present study conceptualizes learning effectiveness of an educational game as a multidimensional concept. As suggested by Kraiger et al. [12], we assume that learning may be evident from changes in cognitive, affective or skill capacities. An important assumption of this approach is that these learning outcomes are not discrete but are usually interacting; changes in cognitive outcomes could for instance co-occur with changes in affective outcomes. Accordingly, evidence of the success of a specific training program may be derived from mean differences between pre- and posttest measures linked with anticipated learning outcomes. Changes in cognitive capacities can be assessed objectively using measures like amount of knowledge and accuracy and speed of recall (accessibility of knowledge). Affective outcomes such as attitudinal and motivational changes can be measured subjectively through self-report (for more details see [12]).

Accordingly, in the present study we combine objective with subjective measures to assess the cognitive and affective outcomes of an educational math game. In order to reach this goal, second graders were randomly assigned to one of three groups: a 'gaming group', a group which was instructed to complete a paper exercises and a control group that that did not receive any mathematical assignment. The experimental design including three groups instead of two (control vs. gaming), constitutes an important methodological aspect of the present study. By comparing paper drills to game playing relative to control condition, we are able to experimentally isolate the effects of the "gaming experience" and thus estimate whether the gaming experience improves arithmetic performance over and above the training effects expected from the classical