**The effects of video-games on students’ motivation to math: A meta-analysis in K-12**

Mathematics is an important and fundamental skill taught in schools; however, there is a decline of enrolment and performance in many countries (OECD, 2013). Reduce a negative perception of math, as well as promote students’ interest and achievement are important challenges that educators have to cope with effective teaching strategies.

One approach that recently received much attention in both, elementary and secondary schools, is the use of educational technologies. Evidence-based research suggested that incorporate technology in the mathematical classroom generally produce a positive effect in comparison to traditional methods, and that the impact is variable by educational technology type (Cheung & Slavin, 2013).

In literature, an increasing number of studies investigated the educational benefits of video games in encouraging mathematical motivation (e.g. Erhel & Jamet, 2013; Kebritchi, Hirumi, Bai, 2010). As stated Prensky (2002), “*students’ motives for learning are a mixture of intrinsic goals and extrinsic rewards, combined with psychological factors” (p.2)* and video-game can stimulate their interest, because play a game is generally engaging (Prensky 2002); it contain challenges, invite curiosity and fantasy (Malone & Lepper, 1987), and encourage students to explore a subject and learning by doing (Annetta et al., 2009).

Motivation, in turn, allow to understand the reasons that lead a student to do a determined task, such as a math homework, and that influence its performance and persistence in the face of difficulties (Wigfield & Cambria, 2010). For example, expectancies for success and related construct as self-efficacy or confidence, that have a central role in many motivational theories (Bandura, 1997; Atkinson, 1957, Eccles et al., 1983), are considered the strongest psychological predictors of achievement in different domains such as math (e.g., Eccles & Wigfield, 2002).

Career aspirations and current activity choice, including taking math classes are instead, mainly influenced by the subjective value placed on the task (e.g., Wigfield & Eccles, 2000). Values considered from the perspective of expectancy-value theory (Eccles et al., 1983), and studied originally in the mathematics achievement domain, are a broad construct that include needs, goals, and motivational orientations and they reflect the importance, interest or utility assigned by various individuals to the same activity. Because individuals tend to engage in valued activities, values have behavioral and motivational consequences (Eccles, 1987).

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**Recent Meta-Analyses…**

**Objectives**

Aim of the present meta-analysis is to answer the following research questions:

1. What impact does the use of an video-game for mathematics education have on students’ motivation towards mathematics?

2. Is the length of the intervention related to video-games effectiveness on changing students’ motivation towards mathematics?

3. Does the type of technological support (personal computer, console, app) influence the success of the intervention?

4. Are there substantial differences depending on level of education (primary vs. secondary)?

**Methods**

The protocol for this meta-analysis was developed according to the Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P; Moher, Liberati, Tetzlaff, & Altman, 2009).

**Eligibility criteria**

In order to answer the research questions, the following criteria were established:

1. Studies characteristics: studies could have taken place in any country, but the report of the study had to be available in English; studies had to have been carried out after 2000; peer-reviewed journal, conference papers and unpublished dissertations were included.

2. Participants characteristics: studies had to be conducted on K-12 students (between 1st to 12th grade); studies conducted exclusively among students with disabilities were not considered because are beyond the scope of this meta-analysis.

3. Interventions characteristics: studies had to use experimental methods with random assignment to treatment and control conditions, or quasi-experimental methods in which treatment assignments were specified in advance. Studies that matched a control group to the treatment group after posttest outcomes (post-hoc quasi-experiments or ex post facto designs) were not included; studies had to compare experimental groups using video-games to control groups using an alternative program already in place, or “business-as-usual”; studies had to provide pretest data.

4. Outcomes characteristics: studies had to report at least one measure of motivation to math; the quality of the instrument had to be validated in the study or in a previous publication.

5. Data: studies had to report: sample size, arithmetic mean and standard deviation of both the experimental and the control groups at the pre/post test to calculate effect size.

**Information sources**

A systematic search for studies on motivation to math through June 2019 was conducted of the following electronic databases: ERIC, OVID: Psycinfo; SCOPUS, EBSCO: Education Source, Proquest. Topic journals archive and reference lists of quantitative studies, literature review, and meta-analyses were also handchecked for additional articles.

**Literature Search**

Terms related to video-games (video game\* or computer game\* or serious game\* or educational game\* or digital game\* or game-based learning) had to be present in the abstract.

Terms related to learning domain (mathematics or math or algebra or arithmetic or geometry or numeracy), grade (K-12 or school or primary education or secondary education), outcome (motivation or engagement), study design (RCT or experiment or quasi experiment or control group or matched groups or effect size) were searched on the full-text. Limits on the search were studies from 2000 to current and English language.

**Study selection and data collection process**

Eligible publications were screened at the abstract levels by three independent reviewers. Publications that reported study clearly irrelevant for the current meta-analysis (e.g. game but not video-game) were eliminated. For the ambiguous cases about potential eligibility (e.g. experimental design) the decision was postponed to the full-text level. In this level all studies previously identified as potentially eligible at the abstract level were screened for final eligibility. In all the steps, the team regularly met up to discuss the doubtful cases in order to ensure the quality of the selection process.

**Summary measures**

Sample sizes, arithmetic means and standard deviations were extracted from the primary studies to calculate a univocal indicator of effect size. Moreover, several study characteristics were coded and data concerning: grade level, type of video-game device and length of the intervention were examined from each study as potential effect size moderators.

**Synthesis of results**

*Calculation of Effect Size:* To estimate the effect size from the initial mean differences, we used the Morris (2008) procedure implemented in the *Metafor* package for R which allows to compute a standardized effect size measure for pretest posttest control group designs. Indeed, the effect size (dppc2) take into account changes in both the treatment and control group and provides an unbiased estimate of the population effect size.

Since the data available from previously published papers in this area were insufficient, the relationship between pretest and post-test scores was set at r = 0.6. We also conducted a sensitivity analysis to ensure that the conclusions from the meta-analysis are unchanged when those correlations are varied.

*Effect Size Aggregation:* To address dependency among effect sizes (e.g., multiple-treatment and multiple-endpoint studies), we used the Gleser and Olkin’ (1994) procedure implemented in the *MAd* package (Del Re & Hoyt, 2014) for R statistics program. A within-study correlation of r = 0.5 was assumed (Wampold et al., 1997).

**Results**

**Study selection**

As shown in Figure 1 (Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group, 2009), eligible publications (n = 1921) were first screened at the abstract level by three independent reviewers; second at the full-text level (n = 165), in which all studies previously identified as potentially eligible at the abstract level were screened for final eligibility.

Several studies (n = 128) were excluded because not focused in math domains or in motivation to math, did not include pre-test, control group or also the control group use video-games. Of the remaining eligible studies (n = 37), some studies (n = 18) were excluded because presented overlapping data (n = 6; in the case of multiple studies we have chosen the most informative one) or not all relevant data (sample size, arithmetic mean and standard deviation) required to calculate the effect size were reported (n = 12).

Authors of these primary studies were contacted to ask for required data, but they did not answer. In all the steps, the team regularly met up to discuss the doubtful cases in order to ensure the quality of the selection process. Finally, 19 studies were identified as adequate for the purpose of this meta-analysis.

**Multiple Effect Size**

In the included publications we found different sources of effect size dependence (Gleser & Olkin, 2009).

*Multiple-treatment study*: Ke (2008) compared multiple experimental conditions (cooperative, competitive and individualistic) with a common control group.

*Multiple-endpoint studies:* Pareto et al. (2011), Riconscente (2013) and Starkey (2013), investigated two different motivational constructs in common subjects, therefore, the effects for these measures were correlated. Four studies (Mavridis, Katmada, & Tsiatsos, 2017; McCue, 2011; Rodríguez-Aflecht et al., 2015; Starkey, 2013) used multidimensional instruments that reflect different aspects of motivational construct. We considered all the dimensions effect sizes, but we accounted for dependence among them.

Concerning other publications, in a study (Ke, 2006) three different treatment conditions were compared with three different comparable control groups; therefore, we analyzed them separately, as independent effect sizes. One study (Chang et al., 2016) reported data from girls and boys separately, but in the analysis we included the combined results; moreover, the authors examined three different sub-domains of engagement (behavioral, emotional, cognitive), but we considered only the emotional engagement related in literature to student interest and values (Eccles et al., 1983; Fredricks et al., 2004). Hung et al. (2014) reported two measures of motivation, but the results of the learning motivation pre-test appeared ambiguous, therefore we considered only data of the self-efficacy questionnaire. Since Riconscente’s (2013) study used a repeated measures crossover design, we considered data to the first half of the study, before the two groups switch. Finally, McCue (2011) examined effects associated with designing and constructing video-games on student attitudes toward mathematics.

**Studies characteristics**

Our research included 19 studies reporting a total of k = 42 effects size which compared effects of use of a video-game for mathematics education with a traditional learning activity (paper-and-pencil) on a motivational outcome; only in the Kim et al.’s (2017) study, the control group task is conducted in a virtual reality learning environment, but involved mainly web-based word problems such as selecting the correct answer by clicking on the potential responses.

Many studies contribute with one effect size, others with more effects, with a maximum of 9 for Starkey’s (2013) study. Despite we collected the studies published since 2000 it was found that no studies satisfying the criteria were published before 2006. It should be noted that most of the studies were published in peer-review journals (see Table 1).

**Participants characteristics**

The samples tested in the selected studies ranging from 40 (Abdelhafez , 2016; Miller & Robertson, 2010) to 1168 students (Rodríguez-Aflecht, et al., 2015). As far as the school grade, the students attend between the 3rd (Pareto et al., 2011) and the 11th grade (Abdelhafez, 2016), and most of the studies focused on primary school.

Gender’s distribution appears well-balanced, but it was not reported in all the studies; should be noted that three studies reported only the distribution of experimental group (McCue, 2011; Miller & Robertson, 2011; Pareto et al., 2011) with a study that tested only 5 girls (McCue, 2011; see Table 1).

**Interventions characteristics**

All the selected studies used a classical pre-test, training, post-test design. In three studies students were randomly assigned to experimental or control conditions (Kim, Ke, & Paek, 2017; Mavridis, Katmada, & Tsiatsos, 2017; Starkey, 2013), while in the other studies sample assignment was occurred at the class level.

The duration of the intervention differed according to the studies from 1 to 28 weeks. Almost all of the samples interacted with the video-game one or two sessions for week, whereas the students of four studies played four/five days for week (Chang, et al., 2016; Miller, & Robertson, 2010; 2011; Riconscente, 2013). Sessions lasting between 20 and 45 minutes, with the exception of Hung et al. (2014) study, which had a learning activity of 240 minutes.

In most of the experiment groups students had access to a personal computer to play educational games (e.g. *Astra Eagle, DimensionM*), while in few cases utilized a console (*Nintendo DS Lite*) or an app (see Table 2).

**Outcomes characteristics**

The studies reported different measures of motivation rated on a Likert response scale (from 3 to 7-point). Several instruments derive or are related to the Expectancy-value theory, as the Keller’s (1987) Attention, Relevance, Confidence and Satisfaction questionnaire (ARCS), utilized by four publications.

Other studies investigated only dimensions related to expectancy, as self-concept (e.g., the Self Description Questionnaire, Marsh, 1992), self-perception abilities (e.g., TOMA-3, Brown, Cronin, & Bryant, 2012) and self-efficacy, or to value (e.g., Emotional engagement, Chang et al., 2016).

Should be noted that for self-efficacy, researchers developed questionnaires inspired by Bandura’s (2000) design guidelines for self-efficacy scales (Pareto et al., 2011), Susan Harter’s (1981) work (Riconscente, 2013) or the Fennema-Sherman’s (1976) Mathematics Attitudes Scales (Hung et al, 2014), that measure confidence, success, usefulness, anxiety and effectance.

The most utilized instrument, in addition to the ARCS of Keller (1987), was the Attitudes Toward Mathematics Inventory (ATMI, Tapia & Marsh 2004) that measure four dimensions related to self-confidence, value, enjoyment and motivation (see Table 3).

**Figure 1.** Flow diagram detailing the article screening, selection, and eligibility process

## Identification

Records identified through database searching  
Educational Source (n = 420)

ERIC (n = 158)

Psychinfo (n = 102)

Proquest (n = 937)

SCOPUS (n = 417)

## Included

## Eligibility

## Screening

Studies included in quantitative synthesis (meta-analysis)  
(n = 19)

Eligible articles excluded for data issues  
(n = 18)

Preliminary eligible studies   
(n = 37)

Full-text articles assessed for eligibility  
(n = 165)

Records screened  
(n = 1921)

Full-text articles excluded because not fulfill the inclusion criteria  
(n = 128)

Records excluded  
(n = 1756)

Additional records identified through other sources  
(n = 61)

Records after duplicates removed  
(n = 1921)

Table 1: Studies and Participants Characteristics

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *cod* | *Authors* | *Publication Sources* | *Effect size estimated* | *Sample size* | *Grade* | *Gender*  *(M/F)* |
| 985 | Abdelhafez (2016) | Dissertation | 1 | 40 | 10-11 | 25/15 |
| 54 | Bai, Pan, Hirumi, & Kebritchi (2012) | Journal | 1 | 437 | 8 | 201/236 |
| 971 | Chang et al. (2016) | Journal | 1 | 90 | 5 | 44/46 |
| 959 | Hung, Huang, & Hwang (2014) | Journal | 1 | 46 | 5 | 24/22 |
| 961 | Ke (2006) | Dissertation | 3 | 358 | 5 | 183/175 |
| 432 | Ke (2008) | Journal | 3 | 160 | 5 | 83/77 |
| 436 | Kebritchi, Hirumi, & Bai (2010) | Journal | 1 | 193 | 9-10 | 102/91 |
| 452 | Kim, Ke, & Paek, (2017) | Journal | 1 | 132 | 4 | 60/72 |
| 476 | Ku, Wu, Lao, Wang, & Chan (2014) | Conference Paper | 1 | 59 | 4 | 26/33 |
| 982 | LaDonna (2018) | Dissertation | 1 | 80 | 4 | 37/43 |
| 988 | Main & O’Rourke (2011) | Journal | 1 | 56 | 4-5 | 25/31 |
| 584 | Mavridis, Katmada, & Tsiatsos (2017) | Journal | 4 | 79 | 7-8 | 46/33 |
| 990 | McCue (2011) | Dissertation | 4 | 43 | 6-7 | 14/5 (e.g.) |
| 611 | Miller & Robertson (2010) | Journal | 1 | 40 | 6 | N/A |
| 610 | Miller & Robertson (2011) | Journal | 1 | 633 | 6 | 143/184 (e.g.) |
| 669 | Pareto, Arvemo, Dahl, Haake, & Gulz, (2011) | Conference Paper | 2 | 143 | 3, 5 | 33/35 (e.g) |
| 935 | Riconscente (2013) | Journal | 2 | 94 | 5 | N/A |
| 983 | Rodríguez-Aflecht, et al. (2015) | Journal | 4 | 1168 | 4-6 | 620/546 |
| 964 | Starkey (2013) | Dissertation | 9 | 168 | 6-8 | 84/84 |

Table 2: Interventions Characteristics

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Authors* | *Weeks*  *(sessions)* | *Minutes for sessions* | *Device* | *Game* |
| Abdelhafez (2016) | 6 (12) | 41 | pc | Math games software |
| Bai, Pan, Hirumi, & Kebritchi (2012) | 18 | N/A | pc | *DimensionM*, 3-D mathematics instructional games |
| Chang et al. (2016) | 2 (8) | 20 | app | Educational game software application, *iOS* mobile devices |
| Hung, Huang, & Hwang (2014) | 1 (1) | 240 | app | Educational games, *Android* operation system |
| Ke (2006) | 4 (8) | 45 | pc | *Astra Eagle*, web-based drill-and-practice programs |
| Ke (2008) | 4 (8) | 40 | pc | *Astra Eagle*, web-based drill-and-practice programs |
| Kebritchi, Hirumi, & Bai (2010) | 18 (18) | 30 | pc | *DimensionM*, 3-D mathematics instructional games |
| Kim, Ke, & Paek, (2017) | 1 | 30-40 | pc | Game-based  learning in a open simulator |
| Ku, Wu, Lao, Wang, & Chan (2014) | 5 (10) | 20 | pc | Mini games |
| LaDonna (2018) | 7 (7) | 45 | pc | *DreamBox* Learning system |
| Main & O’Rourke (2011) | 10 | 20 | console | *Nintendo DS Lite,* *Dr. Kawashima’s Brain Training* |
| Mavridis, Katmada, & Tsiatsos (2017) | 14 | N/A | pc | Educational game |
| McCue (2011) | 28 | 45 | pc | Game programming in MicroWorlds EX |
| Miller & Robertson (2010) | 10 (40) | 20 | console | *Nintendo DS Lite,* *Dr. Kawashima’s Brain Training* |
| Miller, & Robertson (2011) | 9 (45) | 20 | console | *Nintendo DS Lite,* *Dr. Kawashima’s Brain Training* |
| Pareto, Arvemo, Dahl, Haake, & Gulz, (2011) | 9 (9) | 40 | pc | *Teachable Agent Arithmetic Game,* educational game |
| Riconscente (2013) | 1 (5) | 20 | app | *Motion Math, iOS* mobile devices |
| Rodríguez-Aflecht, et al. (2015) | 10 | at least 30 | pc | *Number Navigation,* game-based learning environment |
| Starkey (2013) | 9 (9) | 30 | pc | *Lure of the Labyrinth,* serious digital game |

Table 3: Outcomes Characteristics

|  |  |  |  |
| --- | --- | --- | --- |
| *Authors* | *Instrument* | *Dimensions* | *Items (Likert-scale)* |
| Abdelhafez (2016) | Student Motivation Survey based on ARCS (Keller,1987) | Attention, Relevance, Confidence and Satisfaction | 20 (5-point) |
| Bai, Pan, Hirumi, & Kebritchi (2012) | ARCS (Keller,1987) | Attention, Relevance, Confidence and Satisfaction | 20 (5-point) |
| Chang et al. (2016) | Emotional engagement (Chang et al., 2016) | Emotional Engagement | 33 (4-point) |
| Hung, Huang, & Hwang (2014) | Self-efficacy based on Mathematics Attitudes Scales (Fennema-Sherman, 1976) | Self-efficacy | N/A(5-point) |
| Ke (2006) | Attitudes Toward Mathematics Inventory (ATMI, Tapia & Marsh 2004) | Self-confidence, Value, Enjoyment, Motivation | 40 (5-point) |
| Ke (2008) | Attitudes Toward Mathematics Inventory (ATMI, Tapia & Marsh 2004) | Self-confidence, Value, Enjoyment, Motivation | 40 (5-point) |
| Kebritchi, Hirumi, & Bai (2010) | ARCS (Keller,1987) | Attention, Relevance, Confidence and Satisfaction | 20 (5-point) |
| Kim, Ke, & Paek, (2017) | ARCS – short version (Keller,1987) | Attention, Relevance, Confidence and Satisfaction | 16 (5-point) |
| Ku, Wu, Lao, Wang, & Chan (2014) | Based on Mathematics Attitudes Scales (Fennema-Sherman, 1976) | Confidence | N/A |
| LaDonna, (2018) | Attitude toward mathematics dimension of the TOMA-3 (Brown, Cronin, & Bryant, 2012) | Self-perception abilities and achievements | N/A (4-point) |
| Main & O’Rourke (2011) | Mathematical Self-Concept (Gourgey, 1982) | Self-concept | 25 (3-point) |
| Mavridis, Katmada, & Tsiatsos (2017) | Attitudes Toward Mathematics Inventory (ATMI, Tapia & Marsh 2004) | Self-confidence, Value, Enjoyment, Motivation | 40 (5-point) |
| McCue (2011) | Attitudes Toward Mathematics Inventory (ATMI, Tapia & Marsh 2004) | Self-confidence, Value, Enjoyment, Motivation | 40 (5-point) |
| Miller & Robertson (2010) | Burnett Self Scale (BSS, Burden & Burnett, 1999) | Self-concept | 36 (5-point) |
| Miller, & Robertson (2011) | Self Description Questionnaire (Marsh, 1992) | Self-concept | 20 (5-point) |
| Pareto, Arvemo, Dahl, Haake, & Gulz, (2011) | Self-efficacy scale (Pareto et al., 2011) | Self-efficacy, Liking | 4 , 5 (7-point) |
| Riconscente (2013) | Fractions Self-efficacy and liking (Riconscente, 2013) | Self-efficacy, Liking | N/A (4-point) |
| Rodríguez-Aflecht, et al. (2015) | Math Motivation Expectancy - Values (Berger and Karabenick, 2011) | Expectancy – Values | 14 (5-point) |
| Starkey (2013) | Course Interest Survey (Keller,1987); Mathematics Attitudes Scales (Fennema-Sherman, 1976) | Attention, Relevance, Confidence, Satisfaction; Confidence, Success, Usefulness, Anxiety, Effectance | 34, 60 (5-point) |

**References**

Atkinson, J. W. (1957). Motivational determinants of risk taking behavior. *Psychological Review, 64*, 359-372.

Bandura, A. (1997). Self-*efficacy*: The exercise of control. New York: W.H. Freeman.

Eccles, J., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., et al (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motivation* (pp. 75–146). San Francisco, CA: W.H. Freeman.

Eccles, J.S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53,* 109-132.

Erhel, S. & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Computer & Education, 67*, 156-167.

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education, 55*, 427-443.

Wigfield, A., & Cambria, J. (2010). Students’ achievement values, goal orientations, and interest: definitions, development, and relations to achievement outcomes. *Developmental Review, 30,* 1-35.

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of motivation. *Contemporary Educational Psychology, 25,* 68-81.