Meta-Analysis of Digital Games and Learning In Terms of the NRC's Education for Life and Work Outcomes

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Abstract: This meta-analysis synthesizes research in learning in digital games for students in the K-16 grade range. The studies were located in electronic bibliographic databases from Engineering, Computer Science, Medical, Natural Sciences, and Social Sciences fields. Learning is defined and categorized broadly in terms of the Cognitive, Intrapersonal, and Interpersonal clusters of 21st century competencies outlined in the NRC's recent report on "Education for Life and Work" (Pellegrino & Hilton, 2012). In summary, findings from this meta-analysis indicate that compared to non-game instruction, digital games can enhance student learning as measured by cognitive competencies and some intrapersonal competencies. There was also evidence that certain types of game structures may be more/less effective for certain types of outcomes, underscoring the importance of design beyond simple choice of medium when discussing the affordances of digital games for learning.

Background

In 2006, the Federation of American Scientists issued a widely publicized report stating their belief that games offer a powerful new tool to support education (FAS, 2006). The report encouraged private and governmental support for expanded research into complex gaming environments for learning. A special issue of Science in 2009 echoed and expanded this call (Hines, Jasny, & Mervis, 2009), as have reports by the National Research Council (Honey & Hilton, 2010; NRC, 2009). However, these reports also underscore, that solid evidence for the contributions of games to learning is sparse.

Much of the early debate over digital games for education focused on whether games are "good" or "bad" for education. That question is, however, overly simplistic. The NRC report on laboratory activities and simulations (Singer, Holton, & Schweingruber, 2005) makes clear that the design, and not merely the medium, of a physical or virtual learning activity determines its efficacy. Digital games are a medium with certain affordances and constraints, just as physical labs and virtual simulations are media with certain affordances and constraints. Simulations and digital games actually share many similarities in this regard. Properly designed, these features of games can provide powerful affordances for motivation and learning. Individual studies have shown, for example, that well-designed games can promote conceptual understanding and process skills (e.g., Annetta, et al., 2009; Hickey et al., 2009; Ketelhut et al., 2006; Klopfer et al., 2009; Moreno & Mayer, 2000, 2004), can foster a deeper epistemological understanding of the nature and processes through which science knowledge is developed (e.g., Barab et al., 2007; Neulight et al., 2007), and can produce gains in players' willingness and ability to engage in scientific practices and discourse (e.g., Barab et al., 2009; Galas, 2006; McQuiggan, Rowe, & Lester, 2008). Leveraging these affordances, however, appears to depend on careful design (Clark et al., 2015).

The purpose and need for the current study is threefold. First, a study needs to be conducted that looks specifically at digital games and learning across disciplines and learning outcome types. Second, the study needs to analyze the impact of learning outcomes based on constituent design features as well as the level of game versus traditional instruction such that future development and research can build on that foundation. Third, the study needs to more thoroughly cover eligible studies across fields so that the results do indeed represent this diversity and such that a large enough sample of studies can be collected to reliably explore specific questions of design.

Objectives

This meta-analysis synthesizes research in learning in digital games for students of K-12 age as well as students enrolled at post-secondary educational institutions. The studies were located in electronic bibliographic databases from Engineering, Computer Science, Medical, Natural Sciences, and Social Sciences fields. Learning is defined and categorized broadly in terms of the Cognitive, Intrapersonal, and Interpersonal clusters of 21st century competencies outlined in the NRC's recent report on Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century (Pellegrino & Hilton, 2012). The research questions this study addresses are:

1. What are the effects of digital games on learning for K-16 students?

2. How do these effects vary by learning outcome type in alignment with the categorizations of the recent NRC report on Education for Life and Work (Pellegrino & Hilton, 2012)?

3. How do these effects vary by learning content discipline?

4. How do these effects vary by game type?

Search Strategy

Our database search term criteria simply specified that the terms “game” or “games” needed to be included in the abstract or title. All of other potential terms were deemed likely to inadvertently cut out otherwise eligible studies. In terms of databases, research on games for learning spans many fields. Again we wanted to make sure that we were maximally sensitive in our meta-analysis. We therefore searched the following fields: Engineering, Computer Science, Medical, Natural Sciences, and Social Sciences. To do so, we searched the following databases and sub-databases for the terms “game” or “games” in the title or abstract: (a) ISI Web of Science (SSI and SSSI); (b) Proquest (ERIC, PsycINFO, Soc Abstracts, Social Services Abstracts); (c) PubMED; (d) Engineering Village (Inspec, Compendex), and (e) IEEE Xplore. We also checked the bibliographies in narrative reviews and meta-analyses, as well as those studies that were identified as eligible for inclusion in the meta-analysis.

Selection Criteria

This systematic review and meta-analysis explores the effects of digital games on cognitive, affective, and other learning related outcomes. Eligible studies must describe an eligible digital game program directed toward an eligible participant sample and report information on at least one eligible outcome variable that permits the calculation of an effect size. Each of these eligibility criteria are outlined in detail below:

1. Digital Game. To be eligible, the journal author(s) must explicitly designate the environment as a “game.” The study must focus on the effects of a digital game on an eligible outcome. Games do not need to be to have been designed explicitly as games for learning.

2. Participants. All study participants must be in the K-12 age range of 6 to 18 years of age (whether or not the study was conducted in the context of a K-12 institution), be students in a K-12 institution, or be students enrolled in a postsecondary educational institution.

3. Research Designs. To be eligible for the current meta-analysis, only randomized controlled trial and quasi-experimental designs were eligible for inclusion. (We are simultaneously conducting a parallel review of qualitative research that is not reported here).

4. Learning Outcomes. Eligible studies must report information on at least one eligible outcome related to “learning”, aligned with the recent NRC report on Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century (Pellegrino & Hilton, 2012).

5. Date of Publication. Eligible studies should be relatively modern to reflect the current state of digital game design. Therefore, the date of publication must be from 2000 to 2012.

6. Study Site and Language. The study must be published in English (but not necessarily conducted in English or an English speaking country).

7. Effect Sizes. To be eligible for the meta-analysis, the study must report sufficient information needed to calculate both post-test and pre-test effect sizes.

8. Publication Status. Only peer reviewed journals articles are eligible for inclusion.

Literature Search

All literature searches were conducted in September 2012. Overall, the literature search yielded 61,887 net hits (after accounting for *n* = 7,476 duplicates that were initially identified in EndNote). Most of the reports were identified in ISI Web of Science (*n* = 41,710) or PubMed (*n* = 14,685), although Proquest, Engineering Village, and IEEE Xplore also yielded several thousand results.

A majority of reports were initially screened out at the title level (*n* = 58,111). A total of 3,776 abstracts were next screened for eligibility, and 726 reports were screened and read in full text to determine final eligibility status. Most of the reports were ineligible for inclusion in the meta-analysis due to inadequate research designs (i.e., many were concept pieces that did not empirically examine the effect of a digital game). After screening the full text articles, 80 reports based on analyses of 77 unique data samples ultimately met the eligibility criteria including sufficient information to calculate effect sizes and were included in the final meta-analysis. To clarify some reports include more than one data sample, usually referred to as multiple “studies” within the report, but some reports report on the same data sample as reported on in other reports. The number of reports and the number of distinct data samples is therefore not the same.

Study Characteristics

Games were classified based on the integration of the learning mechanic and the core game mechanic. Interestingly, there were very few games involving fully extrinsic integration of the learning mechanic and core mechanic (a controversial but simple design made famous by the Math Blasters series of educational games where the learning mechanic of solving equations was completely separated from the game mechanic of blasting “space trash” that was the core intended motivator). The learning mechanic of a game can be defined as the primary aspects and interactions within the game intended to support players in learning the target learning outcomes. The core game mechanic can be defined as the aspects and interactions within the game that were ostensibly designed to be the most interesting and engaging aspects of the game. Most of the games were coded as “intrinsic by default” (62%), which meant that the learning mechanic was integrated directly into the core game mechanic but that there were no other elaborate game mechanics due to the simplicity of the game design. “Tetris” would represent an example from this code, as would simple educational games where the player answered questions for points or rewards. Another 36% of the games represented intrinsic integration of learning mechanics and game mechanics in game designs involving more elaborate game mechanics.

Using the broad learning outcome domains from the NRC report on 21st century learning skills, 83% of outcomes measured cognitive competencies, 16% were for intrapersonal competencies, and less than 1% involved interpersonal competencies. In terms of the narrow outcome domains from the NRC report, the majority of effect sizes were for learning outcomes that were measures of knowledge (66%) or cognitive processes/strategies (14%) from the broad cognitive competencies domain followed by work ethic/conscientiousness (10%) and positive core self-evaluation from the broad intrapersonal domain.

Meta-Analysis Comparisons

Overall, the largest body of literature we identified compared digital game interventions with other (non-game) instructional conditions, which are comparisons that may have the greatest relevance to educators (Table 1). Note that a comparison is only significant if the confidence interval does not include “0” within its bounds (e.g., “(.23, 69)” is significant while “(-.36, .18)” is not. Effect sizes associated with non-significant confidence intervals are not significant. Findings from these studies indicated that digital games were associated with significantly better cognitive competency outcomes among students, relative to the other instruction comparison conditions. These beneficial effects on cognitive competencies were primarily based on knowledge outcome measures rather than cognitive processes/strategies outcome measures, of which there were fewer, or creativity outcome measures, of which there were none. Results indicated that game conditions integrating true simple games (i.e., game design involving more than simply draping school tasks with rudimentary game structures such as points and graphics) and those using interface enhancements (i.e., augmentations to the interface through which the player interacts with the game) showed the largest beneficial effects on literacy and general knowledge measures, whereas rudimentary game structures (i.e., game design involving simply draping school tasks with rudimentary game structures such as points and graphics) showed larger effects on science and math outcome measures. There was no consistent evidence that digital games outperformed the other instruction comparison conditions on social science, engineering, or psychology learning outcomes (although there were very few studies focusing on social science or engineering outcomes).

Although there were very few studies reporting findings on intrapersonal competencies outcomes, there was evidence that relative to other instructional conditions, digital games were associated with better intellectual openness and positive core self-evaluation outcomes within the intrapersonal competencies domain. However, no studies provided information about learning outcomes within the interpersonal competencies domain, so there is insufficient evidence to make any statements about the relative effectiveness of digital games for improving interpersonal competencies.

	Cognitive			Intrapersonal			Interpersonal		
Type of game		**95% CI**	**n**		**95% CI**	**n**		**95% CI**	**n**
All games	.32	(.19, .44)	38	.22	(-.04, .49)	8			0
Type of game									
Rudimentary game structure	.22	(.03, .40)	18	.33	(.03, .63)	4			0
Beyond rudimentary game structure	.40	(.24, .56)	20	.16	(-.36, 67)	4			0
Type of game									
Rudimentary game structure	.22	(.03, .40)	18	.33	(.03, .63)	4			0
Integrating true simple games	.78	(.20, 1.36)	3	.46	(-.11, 1.02)	1			0
Situating in virtual context for exploration	.33	(.16, .50)	14	.28	(-.63, 1.18)	2			0
Interface enhancement	.79	(.23, 1.35)	1			0			0
Scaffolding enhancement	.14	(-.27, .56)	2	-.41	(-1.07, .24)	1			0

Table 1. Mean Effect Sizes for Digital Games vs. Other Instruction Comparison Conditions

We then analyzed results from the 12 studies that compared digital game interventions to no treatment control conditions, which indicated no beneficial effects of digital games on learning outcomes. This result was consistent across different outcome domains, subdomains, and disciplines. It should be noted, however, that the failure to detect such effects could be due to low statistical power due to the small ($n < 10$) number of studies that were available for any given analysis. Several additional factors may also have contributed to these findings: (a) the fact that most of these studies focused on psychological assessments involving students with autism or other disabilities, (b) the fact that most of the game conditions implemented in these studies were minimally described, and (c) the fact that these studies often appeared to involve game conditions with low production values. Given these issues, there is insufficient evidence to make conclusions about the (in)effectiveness of digital games on learning outcomes for students, relative to no treatment control conditions.

	Cognitive			Intrapersonal			Interpersonal		
Type of focal game		**95% CI**	**n**		**95% CI**	**n**		**95% CI**	**n**
All focal games	.29	(.10, .48)	13	-.06	(-.29, .18)	9			0
Type of focal game									
Interface enhancement	-.01	(-.36, .34)	4			0			0
Scaffolding enhancement	.47	(.19, .75)	6	-.16	(-.45. 14)	6			0
Player arrangement	.12	(-.25, .50)	3	.10	(-.27, .47)	3			0
Rich context			0			0			0

Table 2. Mean Effect Sizes for Digital Games vs. Other Digital Game Conditions

Finally, we analyzed several studies that compared different designs of digital games to each other (Table 2). In many ways, we view these comparisons between designs as the most important in this study. Much of the debate in the field to date has focused on more simple questions about whether games are good or bad for learning. More productive questions focus on which designs and structures optimize which outcomes for whom and how. The NRC's reports on labs (Singer, Hilton, & Schweingruber, 2005) and games and simulations (Honey et al., 2010) are much more useful when viewed through these lenses. Clearly there are productive designs and unproductive designs of books, labs, movies, simulations, and games for specific goals and people. Nobody needs to be convinced that "bad" games, simulations, books, or labs are unproductive. From our perspective, the most important questions for future research are which design approaches are productive and what affordances are offered within a medium (c.f., Underwood, Banyard, & Davies, 2007).

Our initial findings make clear that there were significantly cognitive learning gains for the various enhanced game designs compared in the constituent studies. Our ongoing work will explore these relationships in greater detail. In terms of our initial findings, there was some evidence that game conditions using scaffolding enhancement (i.e., enhancements to the supports for the player within the game or aspects of the game that adapt to the needs or actions of the player) showed larger beneficial effects on cognitive processes/strategies and knowledge outcomes, relative to those using interface enhancement (i.e., augmentations to the interface through which the player interacts with the game) or player arrangement conditions (i.e., changes in the social arrangements between players ranging from completely individual play to combinations of collaboration and competition). Again, however, there were relatively few (often $n < 10$) studies within any given analysis so it is unclear whether the lack of statistical significance for effects is due to low power or true null effects.

Findings from this report should be interpreted in light of its limitations. The primary limitation of these findings is that most of the analyses were based on a small number of studies (often $n < 10$), and thus it is unclear whether the lack of observed effects in some instances are due to null effects or simply low statistical power to detect such effects. Although meta-analysis often increases statistical power to detect effects by pooling findings across multiple studies, it is nonetheless sensitive to the number of studies and estimated parameters in any given model. Furthermore, the exploratory moderator analyses used to examine whether effects varied across different types of game conditions were likely severely underpowered given the small number of effect sizes within any given subgroup. For this reason, all subgroup analyses were considered exploratory and those results were presented descriptively rather than inferentially. Given these issues with statistical power and limited degrees of freedom, it was also not possible to conduct multivariable meta-regression models to examine whether other study, participant, methodological, or game characteristics were associated with effect size magnitude. In future analyses we plan to explore such multi-variable models for those meta-analyses that included a large number of studies, and at minimum, to explore for possible confounds among different study characteristics. However, the low statistical power to detect effects suggests that the effects measured in the statistically significant comparisons are substantial.

In summary, findings from this meta-analysis indicate that compared to non-game instruction, digital games can enhance student learning as measured by cognitive competencies and some intrapersonal competencies. There was a noticeable lack of interpersonal competency outcomes reported in the literature, so there is insufficient evidence at this time to make statements about digital game effects on those outcomes. There was also evidence that certain types of game structures may be more/less effective for certain types of outcomes, underscoring the importance of design beyond simple choice of medium when discussing the affordances of digital games for learning (just as researchers would assume for any other medium). Furthermore, there was no evidence in any of the analyses that digital games were associated with statistically significant adverse outcomes (i.e., worse learning outcomes).

Please also note that the results reported in this proposal represent preliminary analyses. Between now and the conference, we will be working to double-check all coding and analysis scripting as well as to extend and expand our analyses before we are ready to release the results broadly at the conference. Further analysis is required to investigate why the comparisons of games versus no treatment show a trend of no effect, whereas the comparisons of games versus non-game treatments show an effect. Several possible explanations, including the small number of studies included in the latter group, are discussed earlier in this section. Based on these discussions, we plan to (a) investigate specific questions arising from the analyses to date, (b) investigate issues of study quality and game quality systematically in greater detail, and (c) extensively cross-check all search outcomes, eligibility coding, study coding, and meta-analytic scripting to ensure that this study comprehensively includes all possible eligible studies, that the coding is completely cross checked, and that all analysis scripting is cross-checked.

Acknowledgements

This work was supported by the Games Learning and Assessment Lab – Research (GlassLab-Research) grant from The Gates Foundation through SRI International. The full version of the report is currently in-press at *Review of Educational Research*. Special acknowledgement to the team that assisted in coding and screening including Shara Bellamy, Jamie Eldredge, Lauren Kissenger, Kaitlin Reynolds, Kasia Steinka-Fry, Marriah Vinson, Eric Wilkey, and Stephanie Zuckerman.

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