Multimodality and Interactivity: Connecting Properties of Serious Games with Educational Outcomes

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Abstract

Serious games have become an important genre of digital media and are often acclaimed for their potential to enhance deeper learning because of their unique technological properties. Yet the discourse has largely remained at a conceptual level. For an empirical evaluation of educational games, extra effort is needed to separate intertwined and confounding factors in order to manipulate and thus attribute the outcome to one property independent of another. This study represents one of the first attempts to empirically test the educational impact of two important properties of serious games, multimodality and interactivity, through a partial 2×3 (interactive, noninteractive by high, moderate, low in multimodality) factorial between-participants follow-up experiment. Results indicate that both multimodality and interactivity contribute to educational outcomes individually. Implications for educational strategies and future research directions are discussed.

Introduction

SERIOUS GAMES is an emerging field of scholarship and practices focusing on the use of digital gaming platforms and technologies for purposes beyond pure entertainment.[1,2] Educational games represent a dominant genre in serious games and have progressed and diversified since the early development of "edutainment" titles three decades ago.[3–5] An increasing number of scholars and advocates, such as Jenkins, Gee, Sawyer, and Prensky, have contributed to the improvement of public discourse about the value of digital game–based learning.[6–13]

Despite challenges in the design, implementation, and evaluation of serious games, many practitioners and researchers are enthusiastic about the various possibilities that digital games could offer for learning.[6,9,14–16] They believe these opportunities lie in the nature of digital games and game play, and some also explicate the properties of serious games.[2,10,17,18] Given these advantages, it is often assumed that fun game play experiences would help boost player interest in the subject matter, and this increase of motivation is harvested for deeper and sustained learning.[6,9,16,19,20] However, such assumptions can merely serve as reflections of a utopian view about digital entertainment media, and there is a dearth of empirical research in this regard.[15,21–25] The present study aimed at evaluating the impact of multimodality and interactivity in relation to a set of possible educational outcomes (e.g., shallow and deep, short and longer term), using a unique experimental design and multidimensional measurement approach.

Multimodality and learning

Multimodality is a property of serious games that allows for presentation of content knowledge in a digital gaming environment through a combination of visual, auditory, haptic, and other sensory modalities as well as their manifestations. The degree of multimodality is the number of forms of modality realized in a specific application. Multimodality is an important property of serious games,[17,18] yet empirical research specifically testing the impact of multimodality is limited. Research on computer-mediated communication often compares the social and psychological impact of different modalities such as text and voice[26] but seldom discusses the distinct impact of media formats where multiple modalities are combined in one (e.g., digital games and hypertext). Generally, multimodality helps afford a media environment where users can engage in information processing through multiple sensory channels.[27] Developed by organizational scholars Daft, Lengel, and Trevino, media richness theory proposes uncertainty reduction as a function of the richness of media, part of which addresses the capacity to facilitate

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shared understanding through multiple cues, including communicative modalities.[28,29] Empirical research on learning in multimedia environments suggests that educational content with high level of ambiguity requires richer media to deliver the information in order to achieve better test scores and learning satisfaction.[30] The higher degree of multimodality affords additional channels for information delivery and presentation, which facilitates the sense-making process in learning.[25,31,32] Therefore, the following research hypothesis was proposed:

> **H1: Relative to the conditions with lower level of multimodality, learners in the context of higher level of multimodality will achieve more effective learning outcomes.**

Interactivity and learning

Interactivity is a property of serious games that allows for communication between an individual player and the digital gaming system through different forms of activities. These activities could range from freely exploring the gaming environment, interacting with game elements, to actively seeking information and influencing the trajectories of game play through decision making and subsequent actions. It is a distinct and crucial gaming feature that allows for "more degrees of freedom in communication choices"[33(p170)] (see also Sundar,[27] Grodal,[34] Lee et al.,[35] and Vorderer[36]). Noninteractive format, on the other hand, does not allow for any forms of interaction between player and the gaming system.

These functions of interactivity have critical implications for learning. Interactivity could potentially promote player engagement through both behavioral participation and cognitive processing.[37,38] The behavioral responses in game could help enhance player involvement and participation, thus boosting learner interest and enabling more active learning processes.[39] Instant reactions allow for quick feedback loops to provoke deeper thinking and learning with player engagement in the plot development through dialogues, constant decision-making, and sense-making of previous decisions, which can be limited in television and radio programs due to airtime constraints.[8–10] With player's personal well-being at stake,[19,33] the situated learning becomes more powerful in stimulating and sustaining changes through increased player engagement and participation. Based on prior research, the following research hypothesis was posed:

> **H2: Relative to noninteractive learning conditions, learners in the context of interactive environments will achieve more effective learning outcomes.**

Method

Study design

In order to investigate the specific impact of multimodality and interactivity in the context of common media application formats, we developed a partial 2×3 (interactive, noninteractive by high, moderate, and low in multimodality) factorial between-participants follow-up design with four conditions: (a) game (interactive, high multimodality), (b) game replay (noninteractive, high multimodality), (c) hypertext (interactive, medium multimodality), and (d) text (noninteractive, low multimodality). Game, hypertext, and text represented common media formats widely used in educational settings; replay was a less common media format specifically created for the purpose of this study. All four conditions were developed on the basis of an educational game.

The distinguishing feature about this experimental design is a step-by-step process that allows the systematic feature removal. Comparisons between game and hypertext as well as between replay and text, would provide insight on the particular impact of multimodality. The unconfounded comparison between the game condition and the replay condition would test the specific influence of interactivity.

Participants

Participants were recruited from undergraduates who majored in nonscience disciplines from a private western U.S. university. An iterative sampling strategy was applied to first identify matched pairs for game and replay conditions and then to randomly assign participants to hypertext and text conditions. Matching was based on the participants' digital game literacy, demographic information, and basic knowledge about the subject of interest: the human digestive system.

Participants who did not finish all parts of the study and those whose matched pair (either in game or replay condition) did not finish all parts of the study were excluded from data analysis. In addition, extreme outliers in the control dimensions (e.g., those who had never played a digital game and those who played excessively for many hours a day) were removed from the data set. The final sample consisted of 100 participants with 25 in each condition; 20 males and 80 females, with a mean age of 19.62 years ($SD = 1.61$); all fluent English speakers. Results of an ANOVA with condition as the independent factor confirmed that there were no significant differences across the four conditions with regard to expertise in content area ($F = 0.11$, $p = 0.96$) and digital game experience ($F = 0.35$, $p = 0.79$).

Preliminary analysis confirmed the comparability of participants in all four conditions. There were no significant differences in digital game literacy or baseline knowledge at the beginning of the study. Although all cells included a majority of females, gender composition was consistent across all four cells.

Apparatus

The four conditions—game, replay, hypertext and text—were developed on the basis of a computer game, Metalloman,[40] which was designed to teach concepts and processes concerning the human digestive system to undergraduate students. With an ultimate goal of saving human beings from the attack of alien virus, the player was asked to get inside the human body and accomplish a series of tasks to help the digestive system function.

Replay condition was realized by recording and playing back the game play experiences from the game condition. Since participants in game condition could have very different individual game play experiences, we adopted a unique strategy to avoid confounding the game format with content. Participants assigned to game and replay conditions were matched in sex, age, expertise in the content area, and digital game literacy to control for individual differences. Every participant in replay condition watched the recorded game

play of the other participant of that corresponding match pair. Thus, game and replay conditions provided identical experiences for those matched pair participants except that participants in replay condition did not interact with the game.

Game and hypertext conditions shared the interactivity feature and graphic simulation. However, hypertext did not include visual and acoustic animation through pan/move in the content but consisted of screenshots of the game environment. Text condition was realized as a digital textbook format in which all content information related to the biological processes was included. In accordance with the textbook format, color illustrations of the biological processes were included. Navigation allowed for scrolling through the text at the user's own pace.

Measures

Dependent variables. A multidimensional approach was adopted to capture processes of learning and motivation. First, subjective measures of self-reports on learning and gained interest in the topic were collected on a 5-point Likert scale. Learning consisted of 2 items ($\alpha = 0.89$)—for example, "I learned a lot during the program". For gained interest in topic, 5 items were used ($\alpha = 0.95$)—for example, "The program made me more interested in learning about specific organ systems in the human body (such as physiology)." Both measures of subjective educational outcome were collected at posttest only. Objective measures of knowledge gain were then administered using a 20-item multiple-choice test (with 10 false and 10 correct items) given before (pretest), directly after (posttest), and a week after the program (follow-up test). These knowledge items were piloted on 40 participants, indicating moderate difficulty levels ($M = 52.19\%$). The knowledge items were further divided into eight definition-related items concerning biological *concepts*, eight process-related items concerning biological *processes*, and four items addressing both concepts and processes. Knowledge gain scores for all items, definition items only, and process items only were then computed by subtracting pretest scores from posttest scores as well as by subtracting pretest scores from follow-up test scores. In addition, an essay had to be written after the treatment, prompted by the task to "Describe features and consequences of how our body converts food that we eat into nutrients that can pass through cells and into the bloodstream." The essay was graded by two biology instructors unaware of the assigned condition (range between 0 and 8 points), resulting in a chance-corrected intercoder reliability of $\alpha = 0.94$. Multiple-choice responses were summarized and chance-corrected (sum of correct answers minus sum of wrong answers). Knowledge items and essay were collected at both posttest and follow-up test.

Control variables. For digital game literacy, a factor analysis was performed on the intensity of video/computer/online game play per week reported on a 5-point Likert scale (factor loading 0.88), the average hours of video/computer/online game play per week (factor loading 0.88), and the hours of video/computer/online game play during the week prior to study participation (factor loading 0.84). The resulting factor (eigenvalue = 2.25) explains 75.12% variance. Factor scores were saved and used for the matching procedure.

Expertise in content area was split into two dimensions: domain-specific interest ($\alpha = 0.92$), which included five items such as "I am generally interested in biology," and domain-specific academic performance ($\alpha = 0.82$), including four items such as "I always had some difficulties understanding biology" (reversed). A factor analysis was also performed on these two scales, both resulting in factor loadings of 0.78. Factor analysis explained 60.35% variance and the eigenvalue for the one resulting factor was 1.21. Factor scores were saved and used for the matching procedure.

Other potential influences were controlled with two items each including usability (e.g., "While navigating through the program, I often did not know what to do"; $\alpha = 0.95$), negative emotions elicited by the program (e.g., "I often felt frustrated while I tried to figure out what to do"; $\alpha = 0.90$), motion sickness (e.g., "I sometimes felt sick while I navigated in the game"; $\alpha = 0.95$), and content difficulty (e.g., "I found the program content very difficult"; $\alpha = 0.88$). Finally, total time spent playing or watching the experimental materials was recorded. On average, participants spent 1026.80 seconds on game/replay condition, 649.04 seconds on hypertext condition, and 254.84 seconds on text condition.

Procedure

Participants were recruited in undergraduate classes for extra credit. We first collected baseline information about demographics, media usage, interest in the topic, and academic performance through an online survey. Participants were then invited to attend an individual lab session in which they would first answer an online questionnaire about their prior knowledge of the subject. Then they were asked to play or watch their assigned material (game, replay, hypertext, or text) depending on their individual experimental conditions. To familiarize participants with the navigation tool, all participants in game condition completed a 3-minute technological training session unrelated to the content of the actual game before they started playing the actual game. Participants assigned to other conditions started without training session, since those conditions did not involve unfamiliar controls.

When participants finished playing the game or watching their assigned materials, they were prompted to answer the posttreatment online questionnaire and write the essay. Knowledge items in the pretreatment and posttreatment questionnaires were identical but listed in random order. All lab sessions ended within 1 hour. Participants were thanked and given a goody bag as appreciation of their time. A follow-up online questionnaire including the same measures for knowledge as in pretest and posttest was sent to the participants 1 week after the lab session.

Results

Correlation analysis was performed on both subjective and objective dependent variables. As shown in Table 1, the two subjective measures, self-reported learning and gained interest in this topic, were positively correlated. Among objective measures, only knowledge gain at posttest correlated positively with gained interest.

As the current study adopted a partial factorial design with planned comparisons between some but not all conditions, analysis of covariance (ANCOVA) with a priori contrasts was

TABLE 1. MEANS, STANDARD DEVIATIONS, AND CORRELATIONS ($N = 100$)

Dependent variables	1	2	3	4	5	6
1. Self-reported learning	—	0.56**	0.20	0.15	0.17	0.18
2. Gained interest		—	0.21*	0.18	0.11	0.12
3. Knowledge gain (posttest)			—	0.31**	0.47**	0.16
4. Essay grade (posttest)				—	0.16	0.63*
5. Knowledge gain (follow-up test)					—	0.19
6. Essay grade (follow-up test)						—
Mean	3.10	2.85	1.82	2.66	1.87	1.78
Standard deviation	0.88	0.92	3.61	1.69	3.66	1.37

*$p < 0.05$; **$p < 0.01$.

chosen as the main analysis approach. To explore the impact of multimodality and interactivity on educational outcome, two sets of planned contrasts were performed; the first set used game condition, and the second used text condition as the reference category. Differences were estimated of overall knowledge gain, knowledge gain of definition items, knowledge gain of process items, and essay grades at both posttest and follow-up test, as well as self-reported learning and gained interest, controlling for time spent on the treatment, usability, negative emotion, motion sickness, and content difficulty.

As shown in Table 2, relative to text condition, replay conditions yielded higher knowledge gain (especially knowledge gain of definitions) and higher interest in learning. Relative to game condition, hypertext condition had lower knowledge gain of definition items in the posttest. These two comparisons support our hypothesis that multimodality has a positive impact on educational outcomes. Although the majority of the changes concerned objective measures, participants of replay condition generated more gained interest than those assigned to text condition.

Our hypothesis on interactivity also received some support, as replay condition yielded significantly lower knowledge gain for definition at the posttest and lower overall knowledge gain at the follow-up test. The effect of interactivity was manifested only on objective measures of educational outcomes. Motivational and subjective assessment of learning showed no significant difference.

Discussion

In this study, we adopted a partial 2×3 factorial between-participants follow-up design to empirically test the individual effects of multimodality and interactivity of serious games on educational outcomes among college students. To disentangle multimodality and interactivity, the two features of serious games that are often confounded, we examined four distinct media conditions: game (high in multimodality, interactive), replay (high in multimodality, noninteractive), hypertext (moderate in multimodality, interactive), and text (low in multimodality, noninteractive). Results show some support for the two hypotheses on the educational effects of multimodality and interactivity, most visible in the objective measures of knowledge gain.

Multimodality and interactivity

The biggest contribution of this study lies in the attempt to separate and manipulate interactivity and multimodality experimentally. Although scholars of serious games have acclaimed the benefit of multimodality and interactivity, few studies have tested their effects empirically, mainly for two reasons. First, interactivity is a complex construct to operationalize and manipulate.[21] Second, interactivity and multimodality are often tightly intertwined, making it difficult to attribute any effects to one rather than the other.

The effect of interactivity was mainly examined by comparing the game and replay conditions. We applied a unique matched-pair approach to account for the individualized content produced by a game player. As the pairs were matched for age, sex, digital game experience, and expertise in the subject area, the observed differences between them were attributed to the interactivity of the media format. Interactivity has a significant impact on the definitional knowledge subscale in the posttest and on the overall knowledge gain in the follow-up test. Similarly, the effect of multimodality was examined by comparing game and hypertext as well as replay and text. Overall, multimodality also exhibited a positive effect on knowledge gain both at the posttest and follow-up test. Taken together, this study provides empirical evidence that interactivity and multimodality *individually* contribute to educational outcomes, especially definitional knowledge gains.

Ecological validity

Interpretation of experimental studies is subject to the concern of ecological validity. Although this study disentangled multimodality and interactivity and experimentally tested their individual educational impact, most of the conditions (except replay condition) used in this study are widely adopted in real-life educational settings and thus have important practical implications. The comparisons of game, hypertext, and text conditions do not directly provide support for the impact of multimodality or interactivity alone. Yet they represent different ensembles of media features that collectively produce significant educational impact. Compared to text condition, which is a prototypical media format in traditional educational settings, game and hypertext conditions not only produced higher knowledge gains but also helped elicit higher level of gained interest in the subject matter among college students.

The motivational benefits have important pedagogical relevance. When the media can elicit interest in some content, the likelihood of future learning in this area may be increased. This observation is especially relevant because the current study intentionally involved participants who had no keen interest in the scientific area presented. In fact, most of the

TABLE 2. ANCOVA PLANNED CONTRASTS BETWEEN STUDY CONDITIONS

			Educational outcomes (posttest)						Educational outcomes (follow-up test)			
H	Effects	Condition (reference condition)	Overall knowledge gain	Definition knowledge gain	Process knowledge gain	Essay grade	Self-reported learning	Gained interest	Overall knowledge gain	Definition knowledge gain	Process knowledge gain	Essay grade
	Multimodality interactivity	Game (text)	3.45 (1.54)*	3.63 (0.90)**	0.42 (1.06)	0.73 (0.73)	0.38 (0.36)	1.19 (0.37)**	3.73 (1.53)*	1.19 (0.96)	1.16 (1.05)	0.32 (0.59)
H1	Multimodality only	Replay (text)	3.32 (1.45)*	1.93 (0.85)*	0.94 (1.00)	0.82 (0.69)	0.16 (0.34)	1.05 (0.34)**	1.42 (1.44)	0.45 (0.91)	0.44 (0.99)	0.38 (0.56)
	Multimodality interactivity	Hypertext (text)	2.12 (1.32)	2.08 (0.77)**	−0.05 (0.92)	0.23 (0.63)	0.06 (0.31)	0.86 (0.31)**	1.93 (1. 31)	0.00 (0.83)	1.51 (0.90)***	−0.21 (0.51)
H2	Interactivity only	Replay (game)	−0.13 (1.07)	−1.71 (0.63)**	0.52 (0. 74)	0.09 (0.51)	−0.23 (0.25)	−0.14 (0.25)	−2.31 (1.06)*	−0.75 (0.67)	−0.72 (0.74)	0.07 (0.41)
H1	Multimodality only	Hypertext (game)	−1.33 (1.16)	−1.56 (0.67)*	−0.47 (0.80)	−0.50 (0.55)	−0.32 (0.27)	−0.33 (0.27)	−1.79 (1.14)	−1.19 (0.72)**	0.35 (0.79)	−0.52 (0.44)

Note. Values represent mean differences with standard errors enclosed in parentheses.
$*p < 0.05$; $**p < 0.01$; $***p < 0.1$.

participants reported low interest in biology and did not perform particularly well in this subject. We chose to investigate the educational potential of rather unmotivated students in this study in order to face the often pronounced assumption that serious games would be especially valuable for those populations.[2] Highly interested students, one can argue, perform well in more traditional educational settings (e.g., textbook) and do not necessarily exploit the entertaining surplus of new media.[21] This study indicates that serious gaming could reach out to students who are otherwise more difficult to motivate in a particular discipline (science, in this case).

Educational impact

We adopted a multidimensional approach of measurement to capture the nuances of educational impact. Four different types of measures were used. The two self-reported measures included gained interest and self-reported learning. The two objective measures included a chance-corrected multiple-choice scale containing two subscales focused on definition-related and process-related aspects of the educational content, and an essay question addressing the core content of the media application was used to attain insights into the acquisition of reproducible knowledge.

This set of measures was chosen to include self-reports as well as objective measures and different levels of learning. Further, objective follow-up measures were used to control for the sustainability of educational impact: long-term effect as opposed to short-term effect measured in posttest. The knowledge measures represent an ordinal scale of learning depth ranking from definition subscale, process subscale, to essay. Responding to multiple-choice questions on definitional aspects of scientific content can be considered a more shallow form of learning triggered by rote memory. These items do not require an understanding of the topic but merely a reproduction of correct language. Responses to process-related knowledge measures, however, require an understanding of the scientific concepts and are therefore closer to deep learning.[41] Understanding the concepts and being able to reproduce them in words were required when participants were asked to write their own essays. The essays can therefore be considered the most sophisticated approach to investigate deep learning.[41] This assumption is confirmed by a strong association of the quality in essay writing immediately after the treatment and in the follow-up. Participants who were able to produce an accurate and elaborate essay were likely to produce a similar quality after 2 weeks. This sustained impact was not nearly as pronounced in the multiple-choice measures.

Apart from some differences in gained interest, overall results of the study indicate that the four media conditions produced differences only in the multiple-choice measures of knowledge gain, especially the definitional subscale. There was no significant difference in either process-related knowledge subscale or knowledge essays. Hence, the educational impact elicited through the four media conditions exclusively affected rather shallow learning. By the same token, the sustainability of the elicited effects diminishes over time. As the learning was not deeply enrooted into the participants' knowledge system, their performances after 2 weeks were substantially weakened.

Limitations and future research directions

First, interactivity was operationalized as a dichotomous variable (interactive versus noninteractive). Some scholars have suggested that there are different types and levels of interactivity, the educational effects of which might not be uniform.[25,37] For example, Moreno and Mayer[24,25] and Kalyuga[42] distinguished different types of interactivity that need to work together to produce effective learning. In this respect, game and hypertext conditions may not share the completely identical level of interactivity, which warrants further investigation in more detail. Second, although most of the media conditions tested in this study (except replay) represent media formats widely used in real educational settings, the results of this study are still limited with regard to generalizability. This study examined the effects of media applications only as standalone treatments, without any pedagogical context. Their educational impact might well change when the context of media use (either within or outside the traditional classroom) is taken into account. To address these limitations, future research could try to unpack the concept of interactivity and attribute certain educational outcomes to more specific aspects of interactivity. A fruitful future research direction is to test the educational impact of serious games and other media formats within practical pedagogical contexts. In this way, the effects of digital media properties could be examined in relation to other interacting variables as learning processes unfold in real-life situations.

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