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ABSTRACT
Given the interactive media characteristics and intrinsically motivating appeal, computer games are often praised for their potential and value in education. However, comprehensive research testing these assumptions is still missing. Preliminary comparative studies on the learning effects of games versus traditional media have shown some promise. In this paper, we describe a comparative study that thoroughly investigates the effects of interactivity and media richness on science learning among college students. We also discuss important results and implications yielded from comparisons among four conditions in our experiment (game, replay, hypertext and text).

Categories and Subject Descriptors
K.3.1 [**Computers and Education**]: Computer Uses in Education

General Terms
Experimentation, Design, Paradigm, Verification, Measurement, Human Factors.

Keywords
Digital media, computer games, serious games, entertainment-education, interactivity, media richness, learning effects, education, motivation, replay, hypertext, text.

1. INTRODUCTION
In this entertainment media saturated age, video games and computer games continue to dominate the *play* aspect of people's social life because of their fun appeals. The ubiquity and prevalence of new information and communication technologies have made entertainment products such as games readily available at our fingertips and transformed our consumer experience and notion of enjoyment. In addition, significant advances in sound and graphic cards coupled with increased computational processing power on commodity PCs support the popularity of 3D game engine use and deployment for games and other applications [4] [40].

The growing proliferation of computer games is not a surprise and clearly presents a unique opportunity to tap into and harness the captivating power of play, fun, and enjoyment [47]. Since the 1980's, *Entertainment-Education* represents the effort to optimize socially desirable outcomes (such as learning) through entertainment media [31] [33] [42] [43]. Commercially available entertainment-education offerings have included computer games targeting users generally under the age of ten and primarily improving their knowledge, skills, and the overall learning experiences through play [16]. The emergence of *serious games* broadens the discipline of entertainment-education in numerous dimensions, while keeping the tenet of balancing educating, training, and informing on health and public policy issues through entertainment at the core.

Serious games are being designed, developed, and assessed for a diverse population of users and encompass a broad spectrum of varied content for education, government, health, military, science, and corporate training [29]. A common denominator for advancing the research and development of educational tools like serious games is to leverage from play and entertainment by documenting correlating factors that make serious games effective [32] [36] [37] [47] .

What is so appealing and motivating about playing games? Even serious games? Prior research along with the development and assessment of *Metalloman*, a serious game to teach physiology concepts, sets the stage to examine the interactivity and media richness aspects of game play compared to hypertext and text based instruction. Our comprehensive comparisons among four experiment conditions have yielded interesting results and suggest directions for further empirical testing in this area.

2. RELATED WORK
The concept of educational computer games is not new and their true potential as educational tools emerges particularly because of the fact that 50 to 60 percent of all Americans play games and the typical game players are relatively young and virtually competent computer users [3] [9] [46]. Current attempts have primarily focused on adventure genre or simulation genre. For example, Will Wright's immensely popular *The Sims* and *SimCity* games allow users to play by creating and managing simulated communities and worlds, as well as the personalities that inhabit those environments. *Spore* is another soon-to-be released product by Maxis and developer Will Wright that is a computer simulation game about evolutionary adaptation [28].

Entertainment-Education has largely been responsible for the development of games with learning potential. Most games in this genre are designed to teach reading, math and science skills.

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Examples include educational titles from producers like Knowledge Adventures' *Logical Journey of the Zoombinis, MathBlaster,* and *JumpStart Reading* [11] as well as educational products and associated titles for LeapFrog's *L-Max*™ *Learning Game System* and *Leapster*™ *Learning Game System* [13] to the more recent *FLY*™ Pentop computer.

The MIT's *Games to Teach* project, involving undergraduate students from comparative media as well as seasoned game developers and designers, developed conceptual frameworks of games for math, science, and engineering education [30]. This Microsoft *i*Campus sponsored initiative has led to the development of The Education Arcade, a consortium to expand development work for and assessment studies of games in education [8].

The Serious Games Initiative, which started in 2002 at the Woodrow Wilson Center for International Scholars in Washington, D.C., is most likely responsible for the visibility and popular adoption of the term serious games. Some early examples of serious games to promote health behavior change and management for children include SuperNintendo's *Bronkie the Bronchiasaurus*, an asthma self-management video game; SuperNintendo's *Packy & Marlon*, a interactive adventure video game for children to learn about diabetes self management skills; and *Rex Ronin*, a smoking prevention video game respectively [21]. Not only can serious games be therapeutic for adolescents, they have also proven effective in teaching children a foreign language [1] [34].

Serious games have also been developed for adults to train personnel in a variety of areas. Examples include Visual Purple's *Angel Five*, modeling a weapons of mass destruction terrorist attack with the trainee coordinating resources between federal, state, and local agencies; BreakAway's *Incident Commander* trains first responders and federal employees in the new National Incident Management System for standardized response methods dealing with terrorist attacks or natural disasters; and *Tactical Iraqi*™ which uses artificial intelligence and computer gaming techniques to make learning languages quicker, more effective, and fun for military personnel [44].

Furthermore, there are serious games developed to inform and persuade. For example, the United Nations *Food Force* is a downloadable game about the fight against world hunger [45]. Kellogg Creek Software's *Power Politics* is a U.S. presidential election campaign simulator allowing a player to manage the campaign of the candidate from start to finish by hiring staffers, overseeing advertising, and trying to control the topic of the campaign. Given the proliferation and breadth of serious games activities, clearly the timing is right to investigate features that can validate the effectiveness of serious games as an educational tool.

3. RATIONALE AND METHODOLOGY

3.1 Research Questions

Metalloman is a serious game that teaches physiology concepts to undergraduate college students developed by researchers at the Integrated Media Systems Center (IMSC), an NSF-sponsored center at the USC Viterbi School of Engineering (see Figure 1). The developmental cycle for *Metalloman* has evolved from paper prototypes, pilot classroom implementation and assessment, to our current comparative study. Since specific learning objectives are linked and embedded within the tasks and activities in game, *Metalloman* and the technology supporting it, gives us a glimpse into how and what students are learning [27].

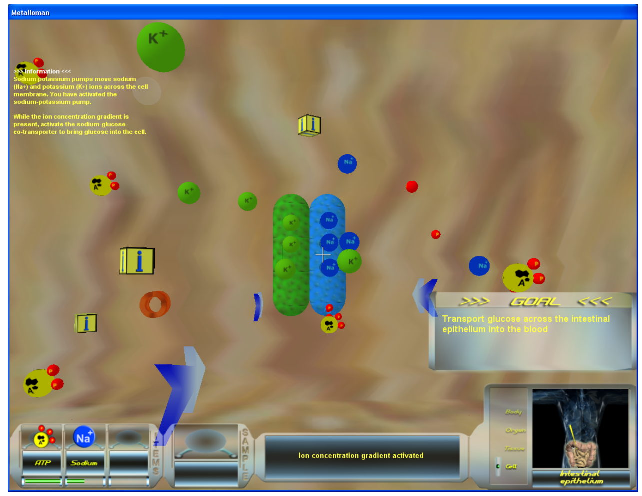

Figure 1. Screenshot of *Metalloman*

Our approach with *Metalloman* addresses the pedagogy of how learning can be conveyed through games without diminishing content while concurrently focusing on how students can *play* with ideas and concepts central to the curriculum. Generally in a game, players are not only presented with information, but *experiences* from which information can be extracted. While that is more complex, it is often more engaging for players and students [18]. The content was carefully designed to simultaneously challenge users with tasks and activities that are tightly coupled to learning outcomes, and to provide an engaging environment supporting curious exploration and an innovative learning experience for students.

To support design and evaluation throughout the development life cycle of *Metalloman*, the hierarchical activity-based scenario (HABS) approach grounded in activity theory was adopted. HABS is a development tool that allows us to plan and model scenarios and narratives [25]. Empirical usability tests have proved *Metalloman* to be supportive, unobtrusive and effective for learning. The content provides access to differing scales in the human body – whether it is the entire body, individual or groups of organs, or even down to molecular details that occur within cells. Navigation through these scales depends on successfully *unlocking wormholes* to gain access.

Mission success during game depends on achieving the goals by performing the following activities:

- Identify sample structure to unlock wormholes,
- Collect substance items, and
- Use substance items to reactivate processes.

Given the interactive nature and rich media format of computer games, *Metalloman* enables its players to identify biological structures and correctly associate them with specific functions for a physiological process, the ability of which is the foundation and a cornerstone for complex science learning.

The conceptual framework for this approach is the *Entertainment-Education* paradigm, in which the contribution of media entertainment for deeper learning is postulated [36] [37] [42] [43]. All forms of play are learning and all forms of learning are play. The separation of learning and play is artificially imposed [17] [36]. The assumption is that there is a relationship between entertainment (enjoyment) and education (learning). The optimal state of this relationship requires a *sweet spot*, in which the entertainment elements function sufficiently enough to serve as a motivator for information processing without distracting people from valuable knowledge content [14] [41] [43] [47].

Interactivity and media richness are considered two most important technological aspects of new media entertainment [2] [7] [20] [24] [15] [38]. Interactivity allows for media richness, which is a generic term including visuals and audios intended to support instruction and to contribute to entertainment [19] [35]. Both factors may contribute to learning by directly allocating attention to educational content, or indirectly increasing enjoyment and thus providing intrinsic motivation for deeper information processing [6] [19] [22] [23] [47]. Interactivity may contribute directly to learning through the opportunity for purposeful navigation and selection of content, as well as indirectly through enhanced enjoyment [5] [12] [39]. The correlation of these entertaining factors, however, is supposed to be mediated through presence, with presence being dependent on usability (see Figure 2).

The present study aims to examine two research questions:

1) Learning effects of interactivity: Specifically, can deeper learning be attributed to an interactive media format versus a non- interactive media format?

2) Learning effects of a combination of both interactivity and media richness: Specifically, can deeper learning be attributed to an enriched interactive multimedia format versus an interactive hypertext format?

3.2 Study Design

A preliminary usability study has shown *Metalloman* to be supportive, unobtrusive and effective for learning [26] [27]. In order to validate these results we decided to take the media effect design a step further. We tried to answer the research questions of *i*) whether interactivity plays a significant role in game-based learning, and *ii*) whether the combination of interactivity and media richness enhance game-based learning outcomes.

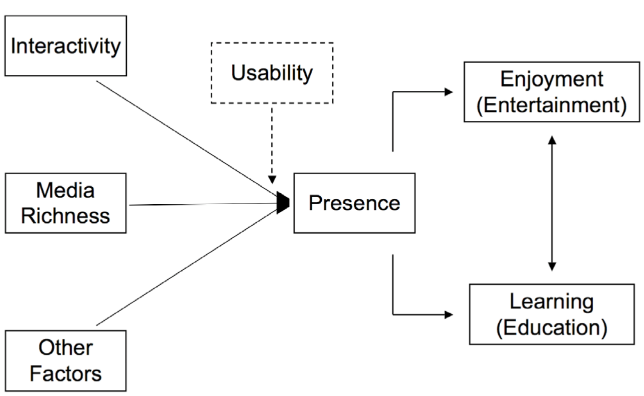

Figure 2. Predictors of game based *Entertainment-Education*

One common training mission and one content-specific mission from *Metalloman* were adopted for the study. The experiment included a total of 100 subjects who were recruited from the University of Southern California undergraduate student body. All participants were non-science majors such as communication, business, psychology, and cinematic arts. As shown in Table 1, the experiment applied a partial 2 x 2 between subject follow-up design, with the factors of interactivity and media richness to address the above research questions. This design allows for the step-by-step systematic removal of features to expose the relationship between entertainment and education.

Table 1. Study design comparing 25 subjects per condition

	High media richness	Moderate media richness	Low media richness
Interactive	Game **(I)**	Hypertext **(III)**	
Non-interactive	Replay **(II)**		Text **(IV)**

Within the interactivity factor, the two independent variables are interactive and non-interactive, by comparing condition I (game) to condition II (replay). Within the media richness factor, the 3 variations are high, moderate, and low in media richness. Results were obtained by comparing condition I participants (game) to condition III participants (hypertext), as well as comparing condition II participants (replay) to condition IV participants (text). Each cell consists of 25 subjects per condition. Furthermore, matching pairs were obtained between condition I and II, and conditional randomization was performed condition III and IV. We controlled for gender, video game literacy, and baseline knowledge in the area of interest so that participants across all four conditions are comparatively homogeneous in terms of gender composition, video game literacy level and prior knowledge of the subject. The matched pair design was realized in recording individual game in condition I and replaying it to a matched subject in condition II. This procedure allowed testing the effect of interactivity while avoiding the confounding effects through varying content. Control factors are based on background results from baseline questionnaires.

Condition I (game) and condition II (recorded gameplay) represent the desktop version of the complete game that varies in interactivity. Participants in condition I (game condition) played the game once, where game play is recorded for play back. Participants in condition II (replay condition) watched the replay of the games played in condition I. Condition III (hypertext) represented a hypertext version of the game including the narrative context and screenshots from the game. Subjects were navigating on their own through the web sites. Condition IV (text) consisted of educational text fragments from the game on the computer screen allowing subjects to read at their own pace and in the order of their choice. This format is enriched with pictures to make it comparable to current textbooks. While this condition was technically non interactive, the user is in control when reading text, with the ability to pause, contemplate, and process ideas presented.

As dependent variables, changes in knowledge and interest in topic were measured. For knowledge measurement, multiple choice questions with ten correct and ten false items on vocabulary, processes, and cause-and-effect relations were presented. In addition, these had weighted difficulty level and were chance corrected. Chance correction included the total of wrong answers subtracted from the total of correct answers. Interest in topic was measured with 5-point Likert scales. In addition, control factors included usability, and resulting negative emotions.

The educational content delivered is identical in all conditions. To determine treatment related changes in knowledge or interest in the topic, a pre- and post-test design was applied in which all items were presented before and after treatment in random order. Finally, a follow-up test one week after the treatment was administered to control for sustainability of effect.

3.3 Results

Preliminary analysis confirm the comparability of subjects in all conditions: There are no significant differences between the baseline knowledge, video game literacy or baseline knowledge at the beginning of the study. Although all cells included a majority of females (ca. 80%), the gender composition is consistent across all four cells hence gender imbalance per se did not affect our interpretation of results.

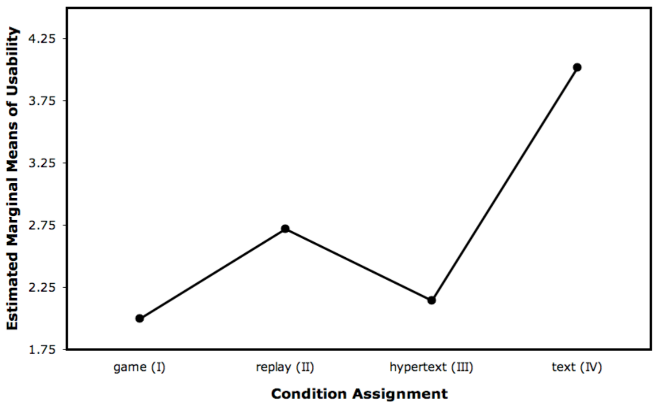

Figure 3. Perceived usability of media format

Usability of the four media formats was significantly different as shown in Figure 3. The mere text version was best usable (M=4.02), followed by the replay (M=2.72), and finally the hypertext (M=2.14) and game (M=2.00) format.

The distinguishing feature about our experimental study design is a step-by-step process that allows the systematic feature removal that will reveal how entertainment and education are related. In addition, the unconfounded comparison between the game condition I (interactivity and high in media richness) versus the replay condition II (non-interactivity and high in media richness) is the only possibility that reveals how manipulating the interactivity feature can have either a facilitating effect or an inhibiting effect because the content remained the same [10].

Matched pair analyses, however, did not reveal any differences for knowledge gain immediately following the lab session (t(24)=.000, n.s.). Neither did we find significant differences in the follow-up test (t(24)=1.67, n.s.) for self-reported learning (t(24)=1.30, n.s.) nor for gained interest in topic (t(24)=.76, n.s.).

An ANOVA with repeated measurement factor for all four conditions, usability and resulting negative emotions as covariates, and knowledge gain as a dependent variable reveals a highly significant main effect for the repeated measurement, F(1;99) = 18.19, p=.000, but no significant main effect for condition or interaction of the repeated measurement and condition (see Figure 4). Although participants' baseline knowledge levels for all four conditions did not show a significant difference, conditions I (game), II (replay), and III (hypertext) resulted in increased knowledge and topic interest, and were able to sustain these effects over time.

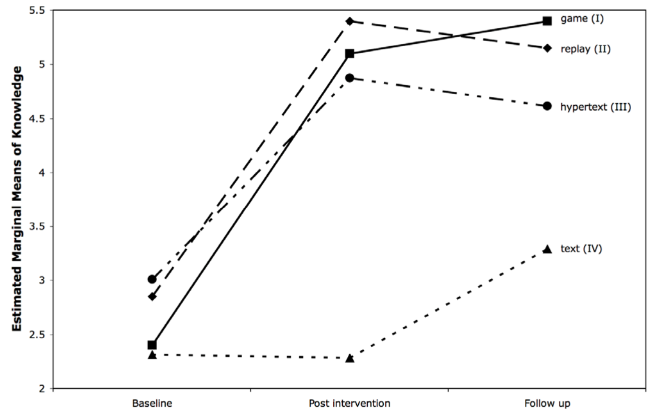

Figure 4. Effects of media format on knowledge gains

By contrast, subjects in the text condition (IV) remained rather unaffected. In comparison with the game condition (I), the text format was perceived as less educational (t(48)=2.08, p<.05), and did not result in a comparable increase of interest (t(48)=2.41, p=.02). In addition, the sustained knowledge gain was smaller in the text condition, t(48)=1.88, although this result is marginal significant, p=.066.

Univariate analysis of variance with the above mentioned covariates (usability problems and resulting negative emotions) for the dependent measures of self-reported learning and gained interest in the topic area were performed. Note that those measures were only applied immediately following the instructional session and not repeated in the follow-up. Results in Figure 5a show no overall main effect for self reported learning, but a significant difference between the game and text version. In a similar fashion, Figure 5b shows gained interest in topic was low in the text format, but comparably higher in the other three conditions.

Analysis of variance applying the same covariates, but presence as dependent variable resulted in a significant effect of the media format, F(3;97)=7.25, p=.000. As indicated in Figure 6, game elicited the highest sense of being in the virtual environment, and text format the lowest.

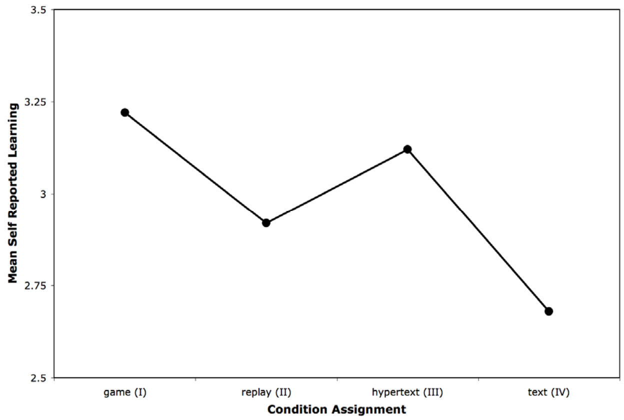

Figure 5a. Effects of media format on self-reported learning

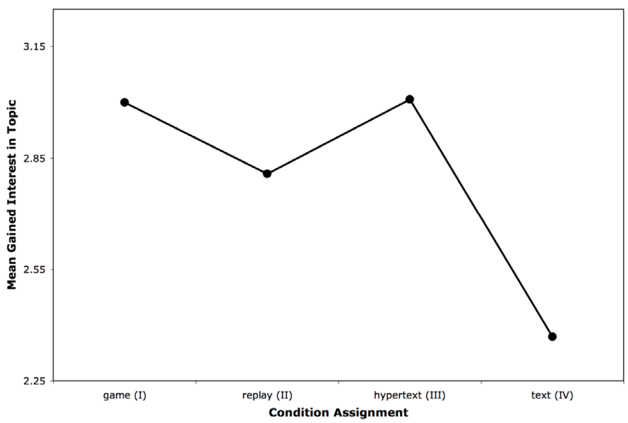

Figure 5b. Effects of media format on gained interest in topic

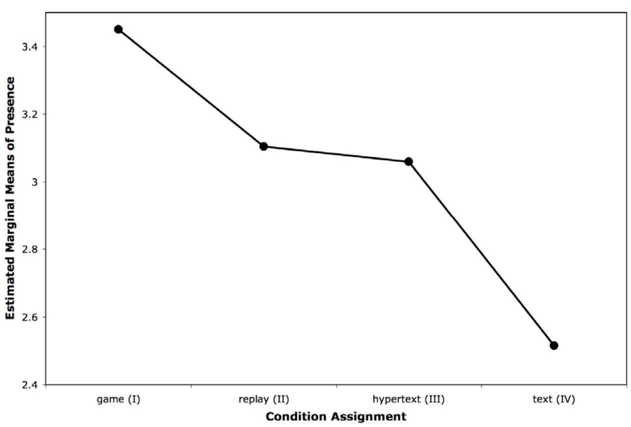

Figure 6. Effects of media format on feelings of presence

Finally, another ANOVA with repeated measurement factor for all four conditions, usability and resulting negative emotions as covariates, was conducted using enjoyment as dependent variable. As shown in Figure 7, our findings reveal a highly significant main effect for the condition, $F(1;99) = 7.4$, $p=.000$. Post hoc comparisons indicate that the text format was enjoyed less than the game, $t(48)=2.74$, $p<.01$.

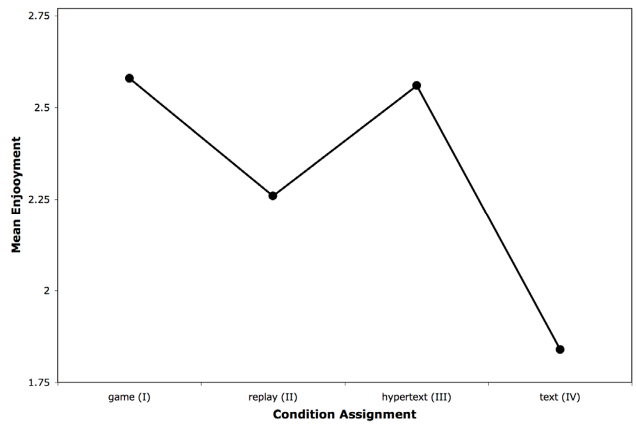

Figure 7. Effects of media format on enjoyment

3.4 Discussion

In contrast to the wide spread belief that interactivity is a crucial factor in media based learning, our findings cannot confirm this assumption. We observed comparable knowledge gains in all enriched media formats: game, replay, and hypertext. Only the mere text version was ineffective in its educational impact. Note that the text consisted of a text book format that includes didactic graphs and pictures to illustrate the content. In sum, our study reveals that new media in general are superior to more traditional presentations of the educational material, here, about biological processes.

The primary assumption of the *Entertainment-Education* paradigm as elaborated above is a blend of educational content with an enjoyable mode of presentation. It is hereby suggested that the processing of factual knowledge can be intensified through the motivational impact of entertainment. Our data support the principle of entertainment-education for new media in general: game, replay, and hypertext were enjoyed much more compared to a traditional text book format. Thus, the same observed pattern holds true for the effects of entertainment and for education.

The unexpected outcome of comparable effects of the three new media formats (game, replay, and hypertext) requires closer attention. First, interactivity did not appear to be crucial for education nor for enjoyment. Although the non-interactive replay condition confronted subjects with a recorded game of a stranger, they seemed to have enjoyed it and profited from it as much as the player him/herself. However, the experience may still have been different: Game players were experiencing more usability issues compared to those who watched the replay. It seems plausible to assume that usability issues provide distraction to content processing. If this holds true it is surprising that the knowledge gain did not suffer in the game condition. We argue that both the game and the replay condition were affected by a component inhibiting content processing: The game through difficulties in usability and the replay through the trials and error of navigation provided by a stranger. Since an observer does not have the privilege of knowing the intentions of the player, s/he must necessarily infer them to be able to understand its inherent logic. Thus, both groups are confronted with media related complexities that may limit their ability to concentrate on the content. On the other hand, the hypertext version was perceived as causing as many usability problems as the game. This observation indicates that the interactive nature of new media, although involving the user through self guided activity, does have a potential of causing usability issues that may contradict the educational purposes embedded.

One possible alternative explanation is the difference in the duration of exposure to the materials. The one hour allotment to subjects in every condition was more than sufficient because all participants finished in less than one hour. The duration of exposure was controlled by the subjects themselves, and was a result of our manipulation of interactivity and media richness. Hence the duration of exposure is a mediating variable, rather than a factor contributing to the variance of dependent variables on its own.

It is also worth noting that the text condition (IV) was operationalized somehow differently from a traditional sense of the "textbook". Text fragments were consumed over a computer screen rather than printed paper, which was designed to keep the medium of delivery consistent across all four conditions. However, we certainly recognize that people are more comfortable with printed out text hence our results should be interpreted with caution.

4. FUTURE DIRECTIONS

One aspect of researching the entertainment value of the *Entertainment-Education* paradigm is the role of non-interactive storytelling in direct comparison to a serious game. Our replay condition II (non-interactive and high in media richness) in this study is a poor approximation of an entertaining movie and having that condition in the future will allow for a direct comparison to reveal whether entertainment embedded with content delivery is preferred.

In addition, data mining and analyses of players interactions for assessment to support the implementation of real-time feedback mechanisms during game are worthy of future research as well.

5. ACKNOWLEDGMENTS

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