Autonomy and Types of Informational Text Presentations in Game-Based Learning Environments

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Abstract. Game-based learning environments (GBLEs) are being increasingly utilized in education and training to enhance and encourage engagement and learning. This study investigated how students, who were afforded varying levels of autonomy, interacted with two types of informational text presentations (e.g., non-player character (NPC) instances, traditional informational text) while problem solving with Crystal Island (CI), a GBLE, and their effect on overall learning by examining eye-tracking and performance data. Ninety undergraduate students were randomly assigned to two conditions, full and partial agency, which varied in the amount of autonomy students were granted to explore CI and interactive game elements (i.e., reading informational text, scanning food items). Within CI, informational text is presented in a traditional format, where there are large chunks of text presented at a single time represented as books and research articles, as well as in the form of participant conversation with NPCs throughout the environment. Results indicated significantly greater proportional learning gain (PLG) for participants in the partial agency condition than in the full agency condition. Additionally, longer participant fixations on traditionally presented informational text positively predicted participant PLG. Fixation durations were significantly longer in the partial agency condition than the full agency condition. However, the combination of visual and verbal text represented by NPCs were not significant predictors of PLGs and do not differ across conditions.

Keywords: Autonomy · Proportional learning gain · Game-based learning environment · Eye tracking

1 Introduction

1.1 Autonomy in Game-Based Learning Environments

Autonomy assumes people, or agents, actively interact with elements in their environment instead of being passive bystanders [1]. There is a need for autonomy within learning environments to promote understanding of content knowledge and skills critical for learning [2]. It is assumed learners who are active within a learning environment can reflect on their progress, whether it be while learning or regulating motivation and emotions, leading to effective planning and the execution of plans to achieve sub-goals [1]. In the context of game-based learning environments (GBLEs)

S. Isotani et al. (Eds.): AIED 2019, LNAI 11625, pp. 110–120, 2019.
https://doi.org/10.1007/978-3-030-23204-7_10

such as Crystal Island (CI) [3], learners are given autonomy to explore and interact with several game elements (e.g., choosing which text and science posters to read, generating hypotheses about potential pathogens, etc.), while also monitoring and regulating their cognitive, affective, metacognitive, and motivational (CAMM) self-regulatory processes, critical for effective learning with GBLEs [4].

As such, self-regulated learning (SRL) involves actively monitoring all thoughts, behaviors, and feelings to then activate and integrate prior knowledge with new information for future planning, monitoring, and achievement of learning goals [5]. Plan development occurs when a goal is made explicit and challenges the learner which increases their motivation to achieve the goal with efficiency [1]. If a goal is not specific, learners with effective SRL skills will identify and modify the plan and strategies used towards achieving the goal [6]. This may include redefining the goals to understand the task demands and steps needed to accomplish the task. In sum, SRL is extremely challenging for most learners, and it is even more challenging in GBLEs where the full agency afforded by these environments can further hinder effective SRL.

The amount of agency afforded to a learner can influence their ability and opportunity to use SRL effectively [2, 7]. GBLEs allow learners to choose how they interact with the environment, specifically while engaging in learning activities, such as reading about microbiology, collecting evidence, engaging in hypothesis testing, learning from biology experts, interviewing patients about their symptoms, etc. [8]. GBLEs are engaging environments for learners to practice SRL skills, accumulate content knowledge, and develop problem solving and reasoning through learning activities [9]. Learners exposed to these environments must monitor their CAMM SRL processes and adapt to the changing demands of the tasks within the environment to ensure successful goal achievement (e.g., identifying the disease causing the illness outbreak in CI). GBLEs are often criticized for their lack of scaffolding provided to the learner, where extraneous details within the game often distract learners from their role and the overall goal of the game [10]. Thus, the level of autonomy afforded to a learner within a GBLE should balance with the scaffolding provided to a learner within the environment [8, 11]. Scaffolding within GBLEs influences developing SRL competencies, where the components of the environment that introduce novel information, such as texts and diagrams, must be selected, organized, and evaluated for relevancy. If relevant, then the novel information is integrated with learners' prior knowledge to achieve their goal.

1.2 Application of the Cognitive Theory of Multimedia Learning to GBLEs

Multimedia learning occurs when the learner constructs a mental representation from the content provided through the combination of words and images presented within an advanced learning technology [15]. Multimedia is typically used to describe learning environments which are enhanced through the use of combining pictures (e.g., photographs, illustrations, and animations) and words (e.g., audio and text) [14]. GBLEs facilitate learners' construction of concepts and knowledge through navigating the environment (e.g., CI) and incorporating information that is received by the learner either through traditionally presented text via large blocks of information or through interactive elements in the environment such as non-player characters (NPCs).

The Cognitive Theory of Multimedia Learning (CTML) [12] can be presented within multimedia environments and their effect on learning processes. This theory is based on three assumptions: (1) visual and verbal/auditory processes have different channels; (2) these channels have a limit on the amount of information that can be processed at once; and, (3) learners actively process information in the environment [13]. In addition to the three assumptions, there is a set of five specified cognitive processes present during multimedia learning: (1) selecting relevant words from text, (2) selecting relevant visuals, (3) developing a mental model for selected relevant words, (4) developing a mental model for selected relevant visuals, and (5) integrating relevant text and visuals into conjoined representations [12]. These cognitive processes are important to note in this model as they require learner utilization of SRL skills (e.g., retention and transfer of learned information) and learner agency for cognitive development [15]. It is important to note that in deeper processing of multimedia presentations, information represented by words can be processed through either the visual (e.g., text) channel along with diagrams and graphs or auditory channel (e.g., spoken language) where they may then cross channels to be organized into either a verbal or pictorial model [10].

The multimedia principle specifically focuses on CTML's first basic assumption, visual and verbal information is processed through separate channels, and third basic assumption which asserts that learning with both channels simultaneously is more effective for deeper understanding than learning with information from a singular channel [14]. The interaction between the learner, more specifically the learner's ability to apply SRL strategies, and the presentation of information should be understood in order to optimally use multiple modes of presentations. This understanding will lead to the examination of the impact that these different modes can have on learning [14]. With both verbal and visual information being presented in conjunction with each other, the learner has a greater chance of recall with the information processed with two separate channels [14].

These channels of information can be presented in multiple ways, including computers and face-to-face interactions with artificial intelligent agents [12]. However, in GBLEs, which offer a unique learning opportunity through direct interaction and exploration of the environment, these presentations can occur through slightly different means. Instructional materials are integrated with the environment so that the learner can interact with the information, which should be regulated to control for the influence the environment can have on the learner and their ability to select and organize critical information for the goal [14]. Traditionally presented informational texts in GBLEs mimic books with blocks of written text appearing on the screen, whereas NPCs, serving as intelligent agents, offer a variation of face-to-face conversations through real-world interactions and character design. Dynamic content (e.g., animation) has found to be beneficial to overall learning outcomes compared to static content (e.g., graphs) when the dynamic content is realistic to the learner [14]. This has been supported through studies [16] to increase support to low-knowledge learners [14]. It has also been applied to GBLEs as the NPCs are typical within the design of GBLEs (refer to Crystal Island Environment section) and can appear to be realistic and provide information crucial to achieving goals. Within CI, participants were also presented with audio as the NPCs interact and answer the prompted questions.

1.3 Eye Tracking in GBLEs

Using eye tracking technology allows researchers to infer cognitive processes, specifically attention and implicit strategies, of a learner through observable behavior [17–19]. Understanding the relationship between cognitive processes and eye movements has become increasingly popular over the past decade, especially in education and science domains [19]. Using eye movements to measure cognitive processes, researchers use two types of measures: saccades and fixation durations [17, 19]. Saccades are rapid eye movements between fixations which can be represented by regressions [17, 19]. Fixation durations result from a relatively still eye motion lasting approximately 250 ms and may produce several variables such as the number of fixations, average duration of fixations, and total time fixating on an area of interest (AOI) [19]. For example, in a GBLE a learner could fixate on specific content within the environment and eye-tracking data captures how many times they fixate on an object, the proportion of time fixating on said object relative to other objects, as well as total amount of time the learner fixates on that object, providing inferences on what the learner may be thinking, the strategies they are using, and whether they are experiencing difficulties [18].

Eye tracking allows researchers to understand relationships between SRL strategy use and learner performance to increase understanding of learner problem-solving processes that occur in GBLEs [17] which introduces a large gap in current literature due to the limited study on these relationships. Problem-solving processes are described by transforming what occurs at the original state provided to the learner to the goal state when there is no evidence of the solution [17]. Past studies have indicated longer fixation durations within cognitive tasks perceived as difficult [19]. This includes problem solving within STEM education. Past research has also concluded improved problem-solving abilities in environments that highlight and emphasize critical components to the goal state [14, 19]. Eye tracking can support inferences about cognitive processes that are used while reading [19]. This can be combined with text structure and content within multimedia theories, such as CTML, to further understand the relationship between SRL strategy use, learning, and the acquisition of content knowledge within these environments [19]. Generally, understanding and integrating content is influenced by perceived difficulty of text and learners' reading ability, which affects eye movements where fixations increase as difficulty of text increases and saccades become shorter [19]. As such, learners' eye movements should allow for inferences in understanding learners' cognitive processes, progress throughout a GBLE, engagement, and SRL strategy use [18].

1.4 Crystal Island Environment

Crystal Island [3], a game-based learning environment, provides an opportunity for students to develop scientific reasoning skills through a microbiology-centered environment where students investigate an illness infecting an island of researchers. Participants are to identify the mysterious illness by interacting with NPCs and reading informational text (see Fig. 1), collecting and scanning food items that may be transmitting the disease, and organizing evidence by completing a diagnosis worksheet.

Once evidence has been gathered, participants make hypotheses about the illness and the source of the pathogen and then test their hypotheses. Once a hypothesis has been tested correctly, the game will end.

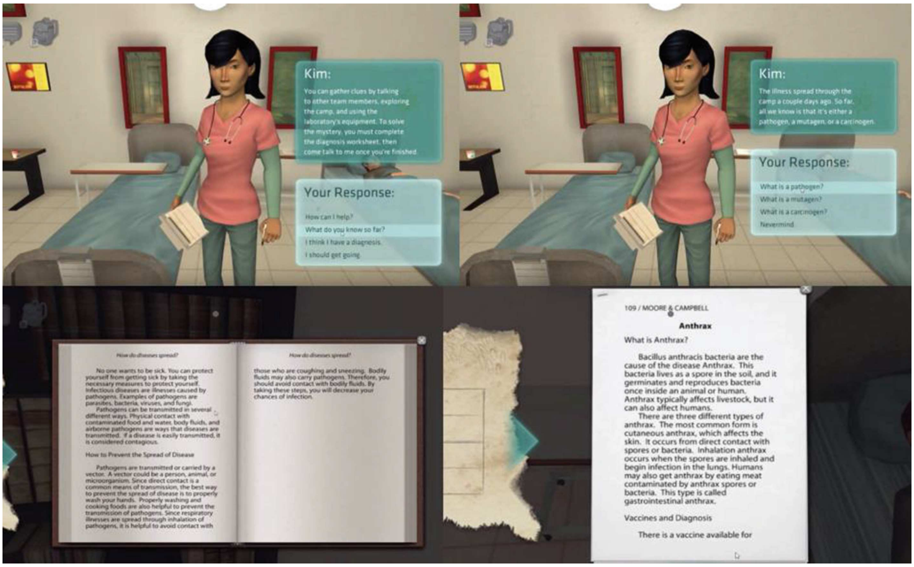

Fig. 1. Top: Informational text presented with an NPC; Below: Traditional informational text presentation

2 Current Study

To assess the role of autonomy and the types of presentation of informational text on PLGs within GBLEs, this study addresses the following research questions: (1) Do PLGs differ between the full and partial agency conditions?; (2) Do fixation durations on different types of informational text presentations in the environment predict PLGs?; and (3) Do fixation durations on different types of informational text presentations differ between the full and partial agency conditions? To address these questions, the hypotheses are as follows:

Hypothesis 1: Participants in the partial agency condition will demonstrate higher PLGs.
Hypothesis 2: The fixation durations of the different types of presentation of informational text in the environment will predict PLGs.
Hypothesis 3: Participants in the partial agency condition will have significantly greater fixation durations of both types of presentation of informational text.

3 Method

3.1 Participants

A total of 106[1] participants recruited from a large public North American university participated in the current study. Fifteen participants were removed due to eye tracking data inconsistencies while one participant was removed for not completing the post-task questionnaires. However, 90 (66% female) undergraduate students recruited from a large public North American university participated in the current study. Ages ranged from 18 to 26 years (M = 20.01, SD = 1.66). Participants were randomly assigned to one of three conditions: (1) full agency (n = 53), (2) partial agency (n = 37), or (3) no agency condition; we did not analyze data from the no agency condition, so details are excluded from this study. These conditions reflected the level of autonomy given to participants to navigate and problem solve with Crystal Island. Participants were compensated $10/h and up to $30 for completing the study.

3.2 Experimental Conditions

Participants were randomly assigned into one of three groups which allowed for varied control of gameplay: full agency, partial agency, and no agency. *Full agency* concedes full control to the participant where they can interact with the game at their own pace and discretion. Participants were free to move from building to building in whichever order they decided as well as choose whether or not to interact with certain game features such as opening a book or collecting a food item to later scan. *Partial agency* contains a "golden path" where participants are required to follow a set path through the game dictating which building to continue to next, requiring participants to interact with non-player characters, and having the participants look at each informational text to complete the concept matrices. For example, once past the tutorial portion of the game, participants in the partial agency condition were directed to the infirmary building first while the full agency participants could go to whichever building they desired. Once in the infirmary, participants in the partial agency condition were required to talk to both NPCs until the conversation options were exhausted, open all posters, books, and research articles, and then accurately complete the concept matrices for all books and research articles. Only after all of these actions were completed, were the participants able to leave the infirmary and directed to go to the next building. The *no agency* condition does not allow control to the participants as the participants will follow a video of an expert run-through of gameplay. This condition was not used in the study as the participants were not able to control for how long they fixated on informational text or NPC dialog.

3.3 Materials

Pre-task measures consisted of a demographic questionnaire and a microbiology pretest. The pretest quiz contained 21, four-option, multiple choice questions

[1] Our dataset derives from a larger study which was modified based on the quality of the data.

developed by an expert in the field. Post-task measures consisted of a microbiology posttest similar to the content knowledge pre-test. The SIM EYERED 250 eye tracker, using a 9-point calibration, recorded fixation duration and gaze movements of participants throughout the task. Log-file data was collected containing participant actions and timestamps.

3.4 Experimental Procedure

Participants read and completed the informed consent. Participants then completed the demographics questionnaire and the microbiology content knowledge quiz. After completion, the research assistant calibrated the eye-tracking device individualized to each participant. The research assistant then explained the scenario of Crystal Island, the role of the participant in the game, the goal of the game, and the actions available to the participant throughout the game, such as reading informational text, talking to NPCs, gathering possible sources of disease transmission, and completing the virtual worksheet. After the participants finished playing, they completed the post-task measures. This consisted of the microbiology content knowledge quiz which was similar to the pre-task version. Participants were then compensated, debriefed, and thanked for their time.

3.5 Coding and Scoring

A data pipeline that temporally aligned the multimodal, multichannel data was used to aggregate data during the experiment. Fixation durations were calculated by predefined areas of interest (AOIs) which included books, research articles, and NPCs. To calculate content knowledge of an individual after gameplay, differences in prior knowledge were accounted for in measuring the learning gains from the post-test score. PLGs are calculated using the pre- and post-test content knowledge scores using a formula accounting for prior knowledge [20].

4 Results

4.1 *Research Question 1*: Do PLGs Differ Between the Full and Partial Agency Conditions?

An independent samples t-test was conducted to compare the means of the PLGs between the full ($M = .218$, $SD = .231$) and partial ($M = .328$, $SD = .245$) agency conditions. There were significant differences in PLG ($t(88) = -2.18$, $p < .05$; $d = 0.46$) where participants in the partial agency condition had significantly higher PLGs than participants with full agency, suggesting those in the partial agency learned more about microbiology compared to those in the full agency.

4.2 *Research Question 2*: Do Fixation Durations on Different Types Of Informational Text Presentations in the Environment Predict PLG?

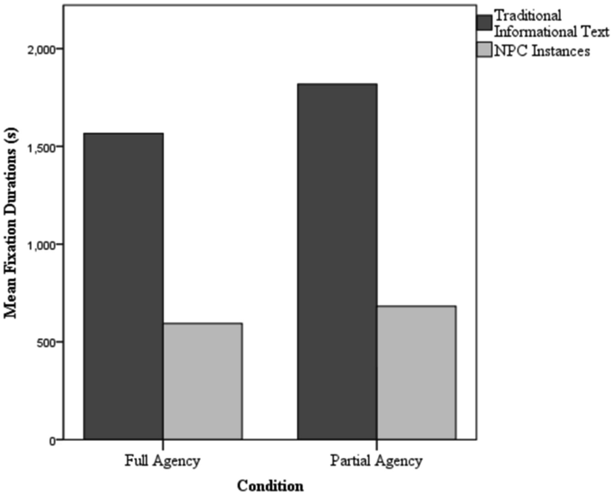

Fig. 2. Mean fixation durations of types of informational text presentation between conditions

A linear regression was conducted to examine whether proportion of time fixating on NPCs over total game time (*M* = .124, *SD* = .035) predict PLG. There was no significant regression equation between the proportion of time fixating on NPCs and PLG ($p > .05$). An additional linear regression was calculated to assess whether the proportion of time fixating on traditional informational text over time (e.g., books and articles; *M* = .319, *SD* = .130) predict PLG. There was a significant positive correlation between the fixation duration of books and articles and PLGs ($r = .233$, $p < .05$), meeting the assumptions for our regression equation, and our results revealed a significant regression equation where the time spent fixating on informational texts was a significant positive predictor of PLG, $F(1,88) = 5.03$, $p < .05$ with an R^2 of .233, indicating that the longer participants fixated on traditionally presented informational texts, the higher their PLG (ß = .233, $p < .05$). In sum, these findings showed that the fixation duration on traditionally presented text is a positive predictor of participants' PLG than the fixation duration of NPC instances, challenging the CTML model where text alone, not the integration of text and diagram, predicts PLGs.

4.3 *Research Question 3*: Do Fixation Durations on Different Types of Informational Text Presentations Differ Between the Full and Partial Agency Conditions?

A MANCOVA was conducted to examine differences in time spent fixating on different types of informational text between the two conditions with total game duration as a covariate (see Fig. 2). There were no significant differences in fixation duration of NPC instances between the full (*M* = 593.84, *SD* = 154.17) and partial (*M* = 682.20, *SD* = 170.52) agency conditions ($p > .05$). However, there were significant differences in time spent fixating on books and research articles, ($F(2,87) = 16.05$, $p < .0005$) between full (*M* = 1565.97, *SD* = 755.05) and partial (*M* = 1851.13, *SD* = 915.84) agency conditions, where the partial agency condition has significantly higher fixation durations than the full agency condition. Overall, these results indicate that the autonomy afforded to a participant influences the fixation duration of the different types of informational text presentation. There were no differences in the fixation duration between types of informational text presentations for the full agency whereas participants afforded partial control of interaction with CI have greater fixation durations of traditionally presented text.

5 Discussion

In support of the first hypothesis, results show that participants in the partial agency condition generally had significantly higher PLGs. This indicates that learners with less autonomy, based on a somewhat prescribed ideal path through game elements allowing for partial agency, is associated with higher overall content knowledge during learning and problem solving with GBLEs. Further, the hypothesis was partially supported when referring to time spent fixating on two types of informational text. NPC instances are not predictors of PLGs, but the fixation durations of traditional information text are significant predictors of PLGs. This indicates that the traditional presentation of information through large amounts of text are better indicators and significantly correlate with higher content knowledge than interacting with NPCs who provide microbiology content knowledge through a more conversationalist approach. This finding runs counter to CTML in which the NPC instances, demonstrating a visual (e.g., the character itself) in conjunction with verbal (e.g., audio and text) information does not predict higher content knowledge whereas just the presentation of text does without the aid of an NPC or audio. This could be explained as the NPC presents verbal information when prompted by the participant that is not as representationally rich as a relevant diagram, and then participants are given small bits of information, but through predetermined prompts the participants may or may not have asked otherwise without room for adjustment of questions. Results partially supported the hypothesis where the partial agency condition had a higher fixation duration when referring to books and articles than the full agency condition, but no difference between conditions when calculating the fixation durations in NPC instances. This indicates that participants who have a set path fixate more on traditionally presentation of informational text over NPC instances. The partial agency condition required the participant to ask every prompt for NPCs as well as open every book and article to complete the concept matrices. From this, participants in the partial agency condition may identify the traditional presentation of text to hold a greater value in the information that is provided.

5.1 Future Directions: More AI in GBLEs?

This study supports the need for integrating more AI in GBLEs to support reading activities that are critical to learning about complex topics such as science. In general, GBLEs should support the development of learners' SRL strategies where the learner is guided by the environment in the completion of the goal, especially critical in GBLEs that afford full agency that may not be beneficial for all learning lacking CAMM SRL skills. As supported by our results, GBLEs that intelligently and actively guide the learner through the environment are needed to optimize proportional learning of complex instructional content. For example, GBLEs are often preferred over traditional learning technologies (e.g., hypermedia) due to perceived affordance to agency, autonomy, and engagement based on constructivist learning models, but our results show that full autonomy is not ideal since most learners do not have the cognitive and metacognitive self-regulatory skills need to make accurate instructional decisions such as when, how, and why instructional text embedded in GBLEs is critical for learning. In addition, our study also demonstrates that the NPCs (acting as intelligent agents interacting with learners) did not provide the information-rich instructional material that was needed and were disregarded, or not engaged with by the learners. The contrast between the roles on informational text and NPS highlights the careful attention that is needed in providing adaptive scaffolding during learning with GBLEs that should be based on time spent on different representations and sequences within and between representations and other related GBLEs activities. For example, information presented through large chunks of text are large components of learner interaction and theses affordances are influenced by the amount of autonomy afforded to a learner when interacting with a GBLE. The study further supports the need for appropriate direction towards the overall goal of the GBLE in order to obtain optimum learning from the learner exposed to the environment. In future versions of Crystal Island, or any text-dependent GBLE, limited, but present support should be given to the learner through the environment to increase the expected content knowledge gain. We envision intelligent agents embedded in GBLEs can play a more active role (a) in assisting learners to select, organize, and integrate instructional content; (b) providing adaptive scaffolding and feedback based on multimodal multichannel trace data from log-files, eye tracking, screen recording, facial expression of emotions, and natural language understanding, and (c) modeling specific self-regulatory processes by prompting and scaffolding students' planning, cognitive strategy use, metacognitive monitoring processes, etc.

Acknowledgements. This research was supported by funding from the Social Sciences and Humanities Research Council of Canada (SSHRC 895-2011-1006). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Social Sciences and Humanities Research Council of Canada. The authors would also like to thank members of the SMART Lab and the intelliMEDIA group at NCSU for their assistance and contributions.

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