The Interactive Effect of Avatar Visual Fidelity and Behavioral Fidelity in the Collaborative Virtual Reality Environment on the Perception of Social Interaction

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Abstract: Collaboration is an important method for online student engagement. Currently employed communication media lack features that foster maximum perception of social interaction in e-learning. New technologies enable researchers and designers to test collaborative learning in the Collaborative Virtual Reality Environment (CVRE), an emerging tool with the potential to provide an interactive e-learning environment. The current study examined how the perception of social interaction in the CVRE is influenced by variations in how much the avatar resembles a human being in appearance and behavior. We measured the extent to which virtual representations were both perceived and treated as if they were human, via self-report questionnaire. Interactive effect for visual fidelity and behavioral fidelity of the avatar was found, suggesting that evaluating the effect of visual fidelity on social interaction without taking into consideration the behavioral fidelity of the avatar (and vice versa) can lead to misleading results.

Key-Words: Collaborative Virtual Reality Environment, Avatar, Visual Fidelity, Behavioral Fidelity, Morphology, Photorealism

1. Introduction

A result of the world-wide communications technology revolution is that the world has become a small town where people can interact and see each other synchronously regardless of location. The development of mobile computing devices such as the laptop, smart mobile phones, and smart PDAs has initiated new methods of interaction and collaboration among e-learners. Consequently, student and teacher interaction in e-learning environments has spread throughout traditional universities and corporate training.

McIsaac and Gunawardena (2001) stated that the explosion of information technologies has brought learners together by erasing the boundaries of time and place for e-learners. Through collaborative learning, learners collaborate with each other about the problem situation in order to construct collaborative learning communities. The fundamental idea of learning communities is that learners must meaningfully collaborate in learning activities through interaction with others. Building a community of learners is an important issue in e-learning because it help learners to converse with peers, present and defend ideas, exchange diverse beliefs, question other conceptual frameworks, and be actively engaged. Smith and MacGregor (1992) illustrated that most collaborative learning activities focus on the learner's exploration and application of the course material, not the teacher's presentation of it. In such learning environment, learners interact with one or more peers to solve a given problem or study something toward the same goal. In addition, a collaborative learning...
Social interaction is a primary factor in building effective learning communities and the achievement of the collaborative learning approach. One strength of e-learning is its ability to facilitate interaction among learners. Anderson (2002) and Peters (2003) argued that social interaction is a major component of collaborative learning because it: (1) plays a vital role in keeping the learning community effective, (2) is essential for knowledge sharing among learners, (3) closes the psychological distance between and among learners while decreasing the learners’ feeling of isolation, (4) enables teachers to identify and meet learners’ needs, (5) affects learners’ and teachers’ satisfaction with the course, and (6) enhances learners’ performance.

Important prerequisites for effective social interaction in e-learning are the visualization of others and the use of non-verbal communication cues. Visualization is important to increase learners’ awareness of the social structure and to visualize other learners and their actions on objects which are common among the learners. Also, the use of the non-verbal communication cues is important because they serve two main functions: (a) conversation management, and (b) the communication of emotion [7, 12].

Technological advances make it possible for learners to meet and interact in a socially rich distributed environment through 3D Collaborative Virtual Reality Environment (CVRE). The use of the CVRE represents a new approach that is intended to evoke emotion in e-learning. Learners can meet, play, and interact synchronously in the CVRE. The intention is to humanize the learning environment by allowing personalities to come across the distance in the process of building a collaborative learning community. CVRE can be defined as a computer-generated multi-user threedimensional interface in which learners can experience other participants as being present in the environment [13]. There are two main types of CVRE: Immersive CVRE and non-immersive / desktop CVRE.

In the immersive CVRE, learners wear a head-mounted display which includes motion trackers to continuously measure the movement and orientation of the learners’ head and allows the image generating computer to adjust the scene representation to the current view. As a result, the learners can look around and walk through the surrounding CVRE. In addition, learners wear a dataglove to interact with virtual world objects and other learners. In the non-immersive / desktop CVRE, a monitor displays the 3D graphics of the virtual world on a 2D screen. Learners typically interact with the virtual world using the keyboard, a mouse, joysticks, or a 3D mouse. This paper is concerned with the non-immersive CVRE.

The research on collaboration in CVRE relates to the field of computer-supported cooperative work (CSCW), which focuses on investigating the impact of using computers to facilitate human interaction. CSCW technology is commonly referred to as groupware, which is defined by Ellis, Gibbs and Rein (1991) as computer-based systems that support learners to engage in achieving common tasks and that provide an interface to a shared environment. Groupware technologies support the activities of multiple learners in the same environment; therefore they encourage group cooperation, collaboration, and partnership.

CVRE researchers believe that its use as a groupware technology in e-learning can add several advantages for both learners and teachers. First, it provides learners with a shared 3D interaction context space. Second, it allows learners to control their point of view by navigating the 3D space. Third, it enables learners to interact with each other in real time. Fourth, it supports geographically dispersed learners to involve in active interaction.

What distinguishes the CVRE from any other communication medium is the existence of the avatar. An avatar is defined as a graphical representation of a human in a multi-user computer generated environment [8]. The potential power of the avatar as learners’ representations in the CVRE is to provide...
learners with a feeling of being physically present in a virtual space that is shared with other learners. Upon seeing an avatar in the environment, the learner immediately sees that avatar as another person. Benford, Bowers, Fahlen, Greenhalgh, and Snowdon (1995) illustrated that without sufficient embodiment, learners only become known to one another through their disembodied actions and disembodied speech. Consequently, the avatar plays a crucial role in the CVRE.

The existence of the avatar in the CVRE satisfies the two prerequisites for social interaction by (1) facilitating the awareness and visualization of self and other learners, and (2) facilitating learners’ nonverbal interaction with each other. The use of avatar in the CVRE will make learners and their non-verbal behaviors visible to themselves and to others. Therefore, Benford, Bowers, Fahlen, Mariani, and Rodden (1994) stressed on the importance of the existence of the avatar in the CVRE in order to provide immediate and continuous information about their presence, activity, attention, availability, mood, status, location, and identity.

Since the avatar is the learner’s embodiment in the CVRE, its effectiveness as learner’s embodiment in the CVRE and its effect on the quality of the perception of social interaction depend on its fidelity. The fidelity of the avatar refers to its ability to mimic the real appearance and behavior of the learner it represents [7]. The fidelity of the avatar can be divided into two categories: visual fidelity and behavioral fidelity. Visual fidelity is concerned with the avatar’s appearance. As presented in Figure 1, visual fidelity is further classified into the categories of (1) avatar morphology and (2) avatar photorealism. Avatar morphology refers to the shape of the avatar in a graphical chat environment. It ranges from humanoid to non-humanoid shapes. Avatar photorealism refers to the level of visual details. Photorealism can range from simple “cartoonish blockies” to highly realistic forms. Behavioral fidelity is the avatar’s animation properties. According to Swinth (2002) behavioral fidelity refers to the extent to which avatars and other objects in a virtual environment behave like their correspondents in the physical world.

Although a number of factors may influence the perception of social interaction in the CVRE, visual fidelity and behavioral fidelity of the avatar have received significant attention. A number of experimental studies have explored avatar fidelity. Bailenson, Beall, and Blascovich (2002) demonstrated that a more realistic looking avatar did not increase interaction compared with a less realistic avatar as long as the avatar demonstrated realistic eye gaze behaviors. Garau, Slater, and Steed (2003) studied avatar photorealism and avatar behavioral fidelity and found that behavioral fidelity is more than avatar level of details. In addition, Garau (2003) found that the avatar with high visual fidelity did not generate a higher perception of social interaction than the avatar with low visual fidelity.

On the other hand, Nowak (2001) and (Nowak and Biocca, 2001) illustrated that the extent to which the avatars resemble real human beings affects participants’ interaction with their avatars and with their partners’ avatars. The partners who were represented by more human looking avatars were rated as more socially attractive and they received higher partner satisfaction ratings than did partners represented by either no image or by an image that did not appear human. In addition, El-said and Mansour (2005) found that the more the avatar resembles a real human...
being, the higher the perception of social interaction.

The contradictory results concerning the impact of visual fidelity of the avatar on the perception of social interaction can be returned to the absence of the distinction between the morphology and the photorealism of the avatar. Therefore, the authors of this paper tried to control the photorealism of the avatar by using avatars which have the same level of details compared to their physical structure in reality while manipulating the morphology by using avatars with different shapes.

The importance of this paper stems from the importance of designing avatars that are developed sufficiently enough to allow the facilitation of a high perception of social interaction among learners. In this study, we examined the interactive effect of visual fidelity and behavioral fidelity of the avatar on learners’ perceptions of social interaction in the CVRE. By conducting this experiment, the authors tried to shed the light on some unexamined issues. This work is intended to expand the evidence that visual and behavioral fidelity of the avatar affect learners’ perceptions of social interaction. Also, this study tends to prove that both avatar visual fidelity and behavioral fidelity have the same level of importance. This study differs from others by: (1) examining the impact of the interaction between the behavioral and visual fidelity of the avatar on learners’ perceptions of social interaction; and (2) controlling avatar photorealism while manipulating avatar morphology.

2. Game Architecture

The CVRE is built using client-server architecture. As shown in Figure 2, the CVRE server provides the logic for the environment and was hosted by The Grand Valley State University, CIS School Web server. The challenge here is to combine the mobile factors with the relatively rich 3D environment and gaming-optimized mobile platform device. Our communications infrastructure relied on the Internet backbone. In order to avoid the usability problems due to latency, we decided to build our gaming scenario where latency became a natural part of the game. This is accomplished by slowing down the movement and reactions of the avatars and by designing a turn-based gaming scenario.

![Figure 2. Client Server Survival Application Architecture](image)

3. Methodology

The study explored the interactive effect of visual and behavioral fidelity of the avatar on learners’ perceptions of social interaction. In this experiment, learners were asked to complete a collaborative task called “Survival”. After completing the collaborative task, learners responded to a series of statements measuring learners’ perception of the quality of social interaction. The independent variables were: (1) visual fidelity of the avatar; and (2) behavioral fidelity of the avatar. The dependent variable was the perceived quality of social interaction. The independent variables were: (1) visual fidelity of the avatar; and (2) behavioral fidelity of the avatar. The dependent variable was the perceived quality of social interaction. The researchers predicted that the avatars which look and behave like a real human being will experience a higher perception of social interaction than avatars that do not look like or behave like real human being.

3.1 Participants

Sixty subjects participated in the experiment. Participants were 25 males and 35 females ranging in age from 18 to 23 years (Mean = 19.58 years). They were of mixed age, gender
and educational backgrounds. Participation was voluntary; incentives for participation were provided at the discretion of the instructor.

3.2 Experimental Design

This experiment investigated two distinct aspects of avatar fidelity: visual fidelity in terms of morphology and behavioral fidelity in terms of animation and non-verbal behaviors. A 3 (shape of avatar) x 2 (level of behaviors) design was employed with one between subjects factor, avatar visual fidelity, and one within subjects factor, avatar behavioral fidelity. The between subjects factor, visual fidelity, included three levels (See Fig.3):

- **Level 1.** Participants were represented by human avatars.
- **Level 2.** Participants were represented by non-human avatars (bird).
- **Level 3.** Participants were represented by object avatars (popper toy).

Figure 3. Types of avatars in the survival environment

The within subject factor, behavioral fidelity, included two level:

- **Level 1.** Participants were represented by static avatars. The static avatar did not have any type of animation except walking. They were unable to neither run or fly nor convey any nonverbal communication cues.
- **Level 2.** Participants were represented by animated avatars. The animated avatars were able to walk, run, fly as well as use the whole body to express non-verbal communication cues such as gestures and body postures. For example, the avatars were able to wave, jump, express joy, express anger, and turn around.

Two variables were controlled: Participants’ computer skills and their previous experiences in using CVRE.

3.3 Instrument

The **Relational Communication Questionnaire (RCQ)** developed by Burgoon and Hale (1987) was used to collect quantitative data regarding learners’ perceptions of the quality of social interaction. The RCQ addresses the immediacy/affection, similarity/depth, receptivity/trust, composure, formality, dominance, and equality. The RCQ questionnaire consists of 25 items with a five-point Likert scale with response options ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire yields a total score that ranges from 25 to 125; a higher score indicates a better perception of the quality of social interaction. The overall internal consistency reliability of the questionnaire is .70. Alpha ranged from a low of .52 for the equality factor to a high of .81 for the immediacy/affection factor.

3.4 Virtual Environment and Task

A collaborative task was employed to stimulate interaction among the participants. The researcher selected the Desert Survival Situation, developed by Lafferty and Eady (1974). This task is widely used as a group development training tool. For this task, participants were asked to imagine they have crash-landed in the Sonora Desert in the middle of summer. He/she and another participant were the only two survivors. They were told ten items had been recovered from the crash and they were asked to find and rank the ten items in order of importance to their survival. Since each group had to agree on one joint decision, the task was seen as fundamentally collaborative in nature. Figure 4 presents snapshots of the Survival environment.
3.5 Equipment

The experiment sessions were conducted in two different labs. Each lab included 20 personal computers linked to a local area network. One participant of each sub-group was seated in the first computer lab and the other participant was seated in the second computer lab in order to avoid direct eye contact between the participants of the same sub-group. Participants communicated verbally through audio using microphones.

3.6 Procedures

Upon arrival, participants were greeted in a reception area by the experimenters. The participants were given two questions to measure their computer skills and their previous experience in using the CVRE. The purpose of these two questions was to reduce potential noise, in general, and effects on group dynamics, in particular. Results of the two questions were used only to assemble the subject groups.

By using the SPSS frequency and percentile functions, the participants were divided into two equal pools. One pool (A) included participants with high scores and the other pool (B) included participants with low scores. Then, participants were randomly assigned to thirty pairs. Each pair included one participant from pool A and the other participant from pool B. Ten pairs were randomly assigned to the human avatar condition, ten pairs were randomly assigned to the non-human avatar condition, and the last ten pairs were assigned to the object avatar condition. Each participant in all pairs was represented by the static avatar at one time and by the animated avatar the other time.

Upon arriving at the laboratory for each session, participants were given an instruction sheet that explained the details of the experimental procedures and any risks associated with using CVRE. After signing the consent form, participants received a brief training session on the navigation of CVRE and the control of the avatars. Participants were given 15 minutes to familiarize themselves with using avatars in CVRE and to prepare themselves for the task. At the end of the 15 minutes, each participant was seated in front of the computer screen in one of two computer labs. This prevented participants from making eye contact while completing the task. Participants were reminded of the amount of time they would have to perform their experimental task.

During the task, the experimenters quietly observed participants. One participant of each pair was assigned to write the final answer for his/her team. In the interest of a standardized procedure, participants were stopped at the end of the allotted 45 minutes regardless of whether the task was completed or not. After completing the task, individual participants completed the RCQ of social interaction.

4. Results

We hypothesized that greater perception of social interaction would be indicated by a higher social interaction questionnaire ratings. Based on the results from previous social interaction studies, we expected Learners who were represented by the animated human avatars would experience higher perceptions of social interaction than learners who were represented by the other five types of avatars (animated non-human, animated object, static human, static non-human, and static object). Based on Blascovich, Loomis, Beall, Swinth, Hoyt, and Bailenson (2002) model of social influence, we expected that the visual fidelity of avatar, namely the morphology, will influence the effect of the behavioral fidelity of the avatar on learners’ perception of social interaction. We expected that the level of the avatar’s behavioral fidelity will be more important for human avatar than for non-human or object avatar.
We performed two-way mixed ANOVA with visual fidelity condition (human avatar, non-human avatar, and object avatar) and behavioral fidelity condition (animated avatar, static avatar) as independent variables and perception of social presence score as the dependent variable. The results indicated a statistically significant interaction between visual fidelity and behavioral fidelity of avatar on learners’ perceptions of social interaction, $F(2, 57) = 41.52, p < .05, \eta^2 = .59$. Figure 5 presents the ordinal interaction between visual fidelity and behavioral fidelity of avatar on the perception of social interaction. An observation worth mentioning in Figure 5 is that as the avatar moved from the human shape to the object shape, the difference between the mean scores of the animated and the static avatar conditions of the same shape tends to decrease. The most significant group is the group that was represented by the human avatars. This group had the highest mean difference between the animated and the static conditions.

Figure 5. The interaction between avatar visual fidelity and behavioral fidelity

Because the two-way mixed ANOVA overall test yielded significant results, post hoc analysis using simple effect analysis was performed to identify where the differences resided. All comparisons were significant at the .05 alpha level. Post hoc test showed significant differences in the RCQ scores between the two animated and static in the human avatar, $F (1, 114) = 206.09, p < .05$, in the non-human avatar, $F (1, 114) = 110.79, p < .05$, and in the object avatar, $F (1,114) = 7.50, p < .05$.

5. Discussion

This experiment sought to investigate the impact of the interactive effect of avatar visual and behavioral fidelity on the perception of social interaction. In terms of appearance, the avatars were either human, non-human, or object. In terms of behaviors, they were either animated or static. Overall, there is an interactive effect of the shape of avatars and their levels of animations on the perception of social interaction. This is evidenced by the statistical results that participants who were represented by the animated human avatars experienced the highest perceptions of social interaction. On the other hand, participants who were represented the static object avatars experienced the lowest perceptions of social interaction.

Participants who were represented by the animated human avatars tended to act as though they were in a real life face-to-face interaction. On the other hand, learners who were represented by the static human avatars were not actively engaged in the interaction process with their partners as in the animated human condition. They perceived their partners, as well as were perceived by their partners as less friendly, expressive, and honest.

The findings confirmed the previous research [2,7] that proved that increasing behavioral fidelity of avatar needs to be accompanied by an increase in visual fidelity of avatar. The non-human avatar demands low-fidelity behaviors, and correspondingly, the human avatar demands a more realistic behavioral model.

6. Implications, contributions, and Future Directions

Earlier we discussed the importance of the avatars in the CVRE and argued that they need to have high visual fidelity and high behavioral fidelity in order to be utilized as effective avatars in the interaction process. This is evidenced by the experimental results showing a
strong significant consistent interaction between visual fidelity and behavioral fidelity of the avatars on the perception of social interaction. The animated human avatars made learners more attached to their and others’ avatars than the static human avatars. It may be inferred that the human avatars benefited from animation whereas the static avatars did not benefit from the human shape. On the other hand, learners who were represented by the object avatars reported a weak significant difference between their perceptions of social interaction in the animated and in the static conditions.

The authors contributed a group of principles composed of recommendations and design principles of avatar in CVRE. These principles are as follows:

− **Avatar morphology.** CVRE should employ human avatars in order to create warm relationships between learner and his/ her avatar and learner and other learners’ avatars.
− **Avatar animation and behaviors:** CVRE should employ avatars which are able to convey learners’ verbal and non-verbal communication behaviors in order to make the interaction process more realistic and true-to-life.
− **Avatar fidelity:** The level of visual fidelity should be aligned with the level of behavioral fidelity of avatar in order to increase rather than to decrease learners’ perceptions of social interaction.
− **Navigation:** Learners should be able to freely move their avatars within CVRE.

Future work may investigate the interactive effect of avatar visual fidelity and behavioral fidelity on learners’ feelings of social presence. Since this study manipulated the morphology by using different shapes of avatars, investigating avatars which varying in the level of details (photorealism) remains an empirical question. A key direction for future research is to examine how variation in photorealism affects learners’ perceptions of social interaction and their feelings of social presence and how it interacts with behavioral fidelity of the avatar.

7. Conclusion

It is clear that avatar fidelity is critical to the development and implementation of the CVRE as a communication tool in e-learning. The experimental results explained the ambiguity in the literature review regarding whether or not the significance difference between the animated and static avatars on the perception of social interaction were due to the avatar morphology. The results indicated that avatars’ morphology and level of animation have a significant positive effect on the perceived social interaction. Implementing a human avatar that is able to convey learners’ nonverbal behaviors is a pre-condition to experience a high perception of social interaction. Understanding the relationship between avatar visual fidelity and behavioral fidelity is essential to begin investigating the use of these new media in e-learning.

8. Reference


