Collaborative Work in 3D Virtual Environments: A Research Agenda and Operational Framework

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Abstract. We propose a conceptual framework based on input-process-output models adapted from traditional group research for the systematic analysis of virtual teamwork. A research agenda contains a list of research questions that will be investigated in a controlled field study in the context of "The ShanghAI Lectures", a global teaching and international student collaboration project. The research questions are formulated regarding processes and outcomes of global virtual teamwork and focus on usability and sociability issues in collaborative work in 3D virtual environments. An operational framework is provided for collecting the relevant data in a structured manner by using qualitative and quantitative process measures of group behavior.

Keywords: Global virtual teams, 3D collaborative virtual environments, group interaction processes, behavioral tracking

1 Introduction

There is a general agreement that getting people to cooperate in geographically dispersed teams is crucial for global organizations in the 21st century [1]. As companies begin to compete globally, virtual teams, which consist of members who work and live in different countries, are becoming increasingly common. They typically do not meet physically but communicate and coordinate their tasks using information technology in order to accomplish their goals [2]. In recent years, 3D Collaborative Virtual Environments (3D CVE) have been developed to facilitate the work process of virtual teams. 3D CVE not only make it possible for virtual teams to communicate synchronously via chat or audio channels but also to perform actions simultaneously using various types of shared applications (e.g., text processor, presentation or spreadsheet programs) while being present in the same virtual room embodied as avatars. The main advantage of 3D CVE is that team members can jointly look at and manipulate objects in a shared virtual space [3].

Popular press indicates that organizations are increasingly using such virtual worlds as a new way to enable collaboration among geographically dispersed work teams [4, 5]. Gartner [6] estimates that 70 percent of all organizations will have established their own 3D virtual worlds by 2012 but reports that 90 percent of corporate virtual world projects fail within 18 months due to an insufficient understanding of the mechanics, dynamics, and the right application areas for virtual world technologies. Therefore, it is crucial that we advance our understanding of how the design of 3D CVE influences group processes and why global virtual teams succeed or fail. However, empirical research on the usability and sociability of 3D CVE is still at an early stage [7, 8].

Our aim is to provide a research agenda, which extends the topics that previous virtual team research has been typically concerned with to the context of 3D CVE [2, 9]. Likewise, we will apply the issues discussed in virtual world research to global virtual teamwork following Kahai et al. [10]. Based on a conceptual framework for the systematic analysis of virtual team behavior, several research questions are derived that focus on the specific usability and sociability issues that emerge from synchronous communication, shared visual representations, and avatar embodiment. An operational framework is provided for collecting the relevant data of group interaction processes in a structured manner by using behavioral observation and coding techniques and a behavioral tracking method.

1.1 "The ShanghAI Lectures" - A Controlled Field Study on Virtual Teamwork in 3D CVE

The context of this research outline is provided by "The ShanghAI Lectures"[1], a higher education initiative using a mixed-reality approach for global teaching and international student collaboration. Its core components are a lecture series on embodied – natural and artificial – intelligence and accompanying multicultural and interdisciplinary task assignments for students. The lectures will be presented by the third author from Jiao Tong University in Shanghai in fall term 2009 and will be broadcast via video-conference to different universities around the globe. Students will collaborate in self-managed global virtual teams on project-based group assignments, view and annotate lectures, and meet with experts, embodied as avatars in a virtual world. In order to comply with the requirements of large-scale global collaboration, a 3D CVE named "UniWorld" is currently being developed at the University of Zurich using *Sun Microsystems' Project Wonderland* toolkit[2] (see Figure 1). This open-source toolkit enables the customized design of the virtual environment, the extension of communication tools (e.g., immersive audio and cameras into the real world [13]) and collaboration features (e.g., virtual team rooms with shared applications), and the implementation of authentication schemes and virtual business cards.

1 http://shanghailectures.org/
2 https://lg3d-wonderland.dev.java.net/

Fig. 1. Snapshot of the “UniWorld” environment. A group of students discussing an instructional video on robotics displayed on a screen in “UniWorld” - the 3D CVE that will be used in “The ShanghAI Lectures”. The screen shot is taken from a pilot study with a prototype of the virtual world.

“The ShanghAI Lectures” also serve as a research platform to carry out studies that are embedded in a general research agenda for the systematic investigation of collaborative work in 3D CVE. The research project aims to explore various aspects of virtual team behavior in 3D CVE and to generate lessons learned that can guide further research. The educational context makes it possible to carry out a controlled field study with experimental manipulation of context factors (i.e. “input variables”) and to administer online surveys and interviews (e.g., using the online evaluation tool “chataca”[3]). In addition, a data collection mechanism is implemented in “UniWorld” in order to spatially and temporally track and reconstruct users' in-world behavior. Behavioral tracking offers the opportunity to collect longitudinal data of in-world behavior in an unobtrusive way [12]. Although the advantages of tracking methods have been recognized by virtual world researchers, behavioral tracking is typically difficult to realize as commercial providers of virtual environments do not allow direct access to their databases [12, 13]. Therefore, observational studies of in-world behavior have mostly used screen recorders, which provide qualitative data that are time consuming to analyze [3]. However, recorded team interactions using *Project Wonderland's* built-in movie recorder provide valuable qualitative information in addition to the quantitative behavioral tracking data. Audio and chat communication data as well as work artifacts (e.g., shared work documents) are stored and can be used for quantitative and qualitative analysis of content.

3 http://www.chataca.com

2 A Conceptual Framework for the Study of Virtual Teamwork in 3D CVE

We propose an input - process - output model adapted from traditional group research [14, 15] that serves as a framework for the discussion of a range of issues surrounding virtual teamwork in 3D CVE (see Figure 2). Input variables can be experimentally manipulated in order to study their effect on group interaction processes and outcomes. The processes during group interactions are expected to have consequences on the individual, intra-group, and inter-group level, which may change over time.

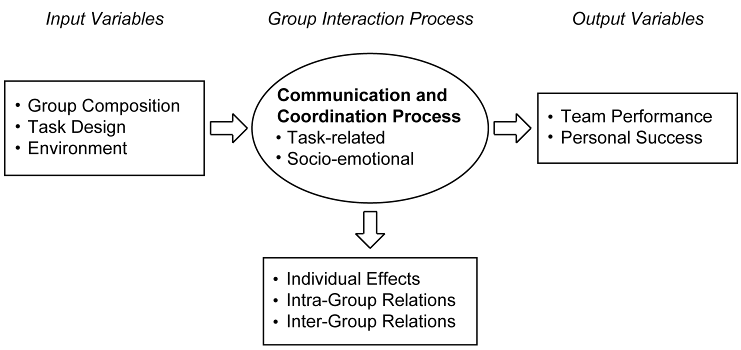

Fig. 2. An input - process - output model of virtual team work in 3D CVE.

2.1 Input Variables

Input variables refer to the composition characteristics of the virtual team, the design of the task, and the context in which the team operates.

Group composition is defined by the number and characteristics of people who are assigned to a team. Team members can differ from one another in their sex, age, cultural backgrounds and associated social norms, technical expertise, or intercultural competences and foreign language skills that are important for global virtual teamwork. In some cases the group structure (e.g., roles or hierarchies) is predefined while in other contexts – as will be the case in “The ShanghAI Lectures” – virtual teams are self-managed with no predefined structure.

Task design refers to the type of the task (e.g., idea generation, problem-solving, decision making or contest) [14], training, resources, supervision, requirements (e.g., the level of autonomy or interdependence required for task completion, or the skills required to solve the task), and task goals (e.g., defined by evaluation criteria of deliverables).

Environmental factors refer to both the virtual and physical space in which groups operate. In 3D CVE the technical environment is a three-dimensional virtual space in which users are embodied as avatars and offered different communication and collaboration facilities. A factor that has often been neglected in virtual team research is the physical environment from which team members access the virtual environment [8]. They can be located at different physical places (e.g., conducting remote work from home or in a shared office) and at different time zones. Both the physical as well as the technical environment pertain to a socio-cultural context in which interactions among individuals can occur.

2.2 Group Interaction Processes

Group interaction processes are characterized by the form and content of communication and coordination between individuals who may belong to the same or a different group. The form of interaction is determined by the communication mode that is used at a given time for a particular purpose. The content of interaction can be task-related (e.g, coordinating task work, seeking information) or socio-emotional (e.g., engaging in personal conversations, providing mutual support). Group interaction processes engender different types of communication and coordination patterns from which consequences emerge for individuals regarding their amount of contribution, the extent to which they experience a sense of social presence and identify with their group. Consequences also arise for relations among group members, such as emerging roles, group cohesion and trust, group norms, and conflict resolution strategies. Group research has often focused on these internal group dynamics and little is known about the context outside of a group [16]. Therefore, we also integrate inter-group relations as defined by conflict and competition or cooperation between members of different groups.

2.3 Output Variables

The outcome of the group interaction process is typically defined as the dependent variable in virtual team research and refers to team performance and personal success. Team performance can be defined by the effectiveness (i.e. quality) and efficiency of teamwork (i.e. productivity as determined by the resources and time needed to accomplish a task). Personal success can be determined by perceived work satisfaction and the acquisition of knowledge and skills. If feedback is provided to a virtual team based on outcome-related evaluations, this may again influence group processes in terms of a new input variable for the following stage in the group interaction process.

3 Research Agenda

The input variables provided in the conceptual framework can be regarded as independent variables to study their effect on group interaction processes and outcomes. For example, we can examine for what types of tasks 3D CVE are most effective or how the group composition influences work satisfaction and team performance by comparing homogeneous and heterogeneous teams. In order to determine factors that contribute to the usability and sociability of 3D CVE we take a closer look at the actual group behavior and team members' subjective experience thereof. The following research questions are non-exhaustive lists of studies that will be conducted in the context of “The ShanghAI Lectures”.

3.1 Behavioral Indicators of High- and Low-Performing Teams

A differentiation of high- and low-performing teams based on their outcomes is required in order to determine why virtual teams succeed or fail. Several research questions can be formulated regarding the following levels.

- *Form and content of team interaction:* Can we identify communication and coordination patterns of high- and low-performing teams, and do they differ regarding the amount of socio-emotional and task-related content?
- *Individual level effects:* Do members of high-performing teams show higher motivation and higher levels of identification with their group? Is the individual level contribution balanced in high-performing teams?
- *Intra-group effects:* Can we find differences between high- and low-performing teams regarding emerging roles (e.g., concentrated vs. shared leadership)? What leadership styles are employed by (emerging) leaders of high-performing teams?
- *Inter-group effects:* Can we find differences between high- and low-performing teams regarding the number and type of inter-group relationships? Do high-performing teams benefit from “weak ties” to other groups [17]?

3.2 Sociability Factors

Sociability is determined by the extent to which a 3D CVE induces a sense of social presence among interacting users and enables team members to interact well with each other – despite the lower “social bandwidth” due to the limited transmission of nonverbal cues (through avatar facial expressions and gestures), which are crucial for the transmission of meaning, conversational management, and the expression of emotional states. Besides analyzing what types of relationships are formed during group interactions, sociability analysis should also focus on how those relationships are performed in shared activities [18]. The following factors are assumed to contribute to the sociability of 3D CVE and appear worthwhile to be investigated:

- *Perceived presence:* How well do users identify with their avatars and do they feel present in the virtual environment? Does perceived social presence facilitate the establishment of group cohesion and trust among team members?
- *Social conventions:* Are there any cultural differences regarding what behaviors in the virtual space are perceived as effective and appropriate? Do

social conventions that can be observed in face-to-face interactions (e.g., proxemics) transfer to the virtual environment [13]?

- *Relationship formation:* What types of relationships occur and how do they change over time? Are there any cultural differences in the way relationships develop?
- *Emerging roles:* What roles are emerging during group work? Can we identify a set of behaviors that determines particular emergent roles, such as leadership?

3.3 Usability Factors

Usability can be defined as a precondition for team effectiveness and efficiency, and refers to the extent to which the technological environment supports successful team performance and work satisfaction. In order to identify user needs to derive design guidelines for 3D CVE, we need to investigate what virtual teams actually do and how they use the communication and collaboration facilities provided by the 3D CVE [8]. The following research questions provide insights of how users cope with the environment and may highlight possible usability issues:

- *Communication modes:* What communication modes (audio and chat) are being used, how often, by whom, and accompanying which tasks?
- *Collaboration tools:* What collaboration tools are being used, how often, and for what purpose? What problems occur when using these tools?
- *Support facilities:* What types of support (e.g., technical, conflict mediation, task-related) are most requested, by whom, and at what stage of teamwork?
- *Perceived usability:* How does team members' subjective experience of technical and social aspects of 3D CVE interactions relate to observed behavioral patterns of virtual teamwork?

4 Operational Framework for the Study of Group Interaction Processes in 3D CVE

The analysis of group interaction processes requires multiple measurement times or continuous measurement as they are likely to change over time – and these changes are the main objects of interest. For example, the analysis of emerging roles and relationships require either subjective reports by team members or the collection of longitudinal behavioral data and cannot be measured at a single post-process measurement time. In order to observe group interaction processes, the acts and roles of collaborative people have to be made explicit [8], which calls for different types of behavioral observation tools that will be discussed below. Due to space restrictions, we limit our discussion to objective behavioral measures and leave out self-report methods that are typically used in virtual world studies and critically discussed elsewhere [19].

4.1 Behavioral Coding of Video-Recorded Interactions and Communication Artifacts

Some research questions require the analysis of content-related behaviors based on video-recorded interactions or communication artifacts. For example, the content of group interactions is relevant in order to extract information about the frequency of socio-emotional and task-related processes, to identify leadership styles, the kind and frequency of conflicts that occur and what strategies teams employ to resolve them. Bales' Interaction Process Analysis [20], the classic behavioral coding system, provides guidelines for collecting quantitative data from recorded observations, which require manual classification of content-related behavioral units. Specific coding schemes also exist, for example, to identify different leadership styles based on communication artifacts (e.g., the Leaderplex framework adapted to virtual team research [21]). In addition, qualitative analysis of video-recorded fragments of team interactions can be used for detailed description of the group dynamics involving all behavioral aspects of the social interaction within the given context [3].

4.2 Behavioral Tracking for Automated Quantitative Data Collection

When open-source tools, such as *Project Wonderland*, are being used to build a 3D CVE, temporal and spatial activities of users do not have to be coded manually by investigators but can be automatically tracked by the system and can be exported from the database for sequential analysis of in-world events and shared activities:

- *Temporal tracking* includes the frequency and duration of events or actions that users perform either individually or in cooperation with others.
- *Spatial tracking* captures all aspects of avatars' locomotion (i.e. position and movement), also providing information about visited virtual places.
- *Event tracking* registers the type of activities users engage in (e.g., using shared applications for collaborative writing, drawing, or programming, watching a movie on a screen, annotating video-recorded lectures, reading FAQs for different types of issues, exchanging virtual business cards, etc.)

It is important to consider that groups do not interact – but individuals do. Therefore, we track and analyze group interaction processes based on the actions that individuals perform. In order to analyze communication and coordination patterns and emerging relationships among individuals, the frequency and duration of (inter)actions can be tracked, which requires meta-data such as time stamps, the number of participants involved, and possibly where the interaction took place. These data can then be analyzed at the dyad or group level, or between groups (see Figure 3). We suggest to generate separate interaction matrices for chat and audio communication, and for coordination of shared actions. For example, the number of messages exchanged within a group of actively participating individuals can be taken as a measure of "interaction intensity" between the members of that conversational group. At the individual level, the number of messages sent or amount of speech can be used as an indicator for the individual's level of contribution. The interaction intensity between any two users can be tracked over time and statistically aggregated to estimate the strength of intra-group or inter-group relations. The analysis can be carried out for different time spans, for example, for multiple team meetings in order to observe changes in communication intensity among team members over time. However, it has to be taken into consideration that the quality and quantity of a team's output can be expected to higher than the aggregated individual contributions.

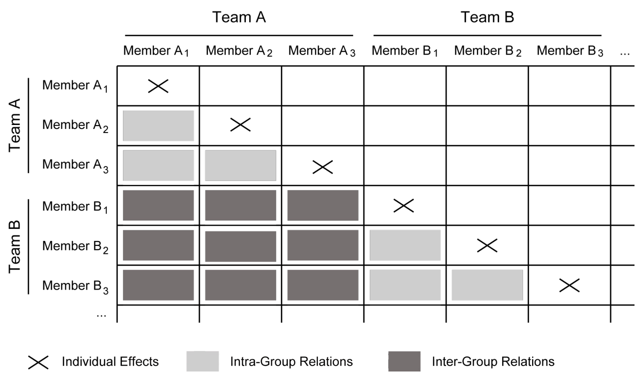

Fig. 3. Interaction matrix based on communication and coordination intensity calculation.

In order to study inter-group relations in 3D CVE, the design of the virtual world has to be taken into account, which determines how much access users have to one another and how different virtual spaces foster the density of networks [22]. We also have to differentiate between focused collaboration (i.e. active participation) and unfocused collaboration (i.e. monitoring of group activities without getting involved) [8]. Furthermore, the duration of an interaction does not necessarily imply higher effectiveness but can be an indicator for misunderstandings between team members, possibly due to language barriers. Therefore, quantitative tracking data and qualitative analysis of group interactions should be used in complementary fashion in order to gain a better understanding of how virtual teams work in 3D CVE as both methods have their limitations.

5 Conclusions

The conceptual framework and the illustrations of the ways in which it can be used to derive relevant research questions show the importance of a theoretical foundation for research on collaborative work in 3D CVE. We believe that the automated behavioral tracking approach is an important step towards the systematic analysis of group interaction processes. However, there are still open issues to be resolved on how to best combine and statistically analyze the large amounts of behavioral data in order to derive guidelines on how to effectively plan, structure, and support the work of globally distributed teams in 3D CVE.

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