The impact of Awareness Tools on Mutual Modelling in a Collaborative Game

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Preface

This report is my master's thesis presented in order to obtain a DES in Sciences et Technologies de l'Apprentissage et de la Formation (Master of Science) at the University of Geneva. The work was performed from November 2001 to October 2002 in Lyon and Geneva. The thesis topic comes from my previous work on awareness tools in video games, done as an assignment for a course in our master in May 2001. I also would like to mention that this research was conducted in partnership with the Geneva Interaction Lab (GIL).

Since this document is my first attempt to write in english, I would like to apologize for all my mistakes.

I wish you a merry reading and a happy new insight in this field of research.

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Abstract

This dissertation describes the findings of an experimental research concentrating on collaboration in a multi-player game. The overall goal is to study the cognitive impacts of the awareness tools. The focus is in finding an effect on performance as well as on the representation an individual build of what his partner knows, plans and intends to do (i.e. mutual modelling) while performing a joint activity. The research methods used are quantitative. In the context of the game, we found that using a awareness tools has a significant effect by improving task performance. However, the players who were provided with this tool did not show any improvement of their mutual modelling. Lastly, further analysis on contrasted groups revealed that there was an effect of the awareness tool on mutual modelling for players who spent a large amount of time using the tool.

« Man the food-gatherer reappears incongruously as information-gatherer. In this role, electronic man is no less a nomad than his Paleolithic ancestors »

- Marshall McLuhan, 1964

« We ought to make backups of our society before jumping into the black hole of virtuality »

– Bruce Sterling, interview, 19-9-1995

Introduction

With the rising use of Information technology (IT), work becomes ubiquitous, and the notion of distributed virtual teams emerged. To fit the needs of distributed organizations, **multi-user environments allow people to work together from different places at the same time** (Ellis et al., 1991). Those devices must support interactions of users in order to enable a fluid collaboration between them and to overcome the limits caused by the lack of co-location (Cramton, 1997). Thus the field of CSCW (Computer Supported Collaborative Work) designs systems that support collaboration and communication among large groups of participants. Groupware systems are an example of such devices; Sohlenkamp (1999) defines it as "any software supporting the cooperation of several users through the computer medium". Multi-player games are another example; instead of working, users employ those programs for enjoyment.

It is worth pointing out that there is an interesting paradigm shift: from a human-computer interaction perspective to a human-human interaction perspective. Collaboration and communication over computer networks must take in account social interactions. In this respect, Erickson and Kellog (2000) call "*socially translucent systems*" those multi-user environments that support coherent social behaviour. Groupware systems and computer games can no longer been seen as a support for isolated activities. In addition, concerns have been raised that we should now reconsider the boundaries of the unit of analysis for cognition. Hollan et al. (2000) claims that individuals, artefacts and their relations to each other in an environment form a functional system, that is to say a single cognitive system. The authors call "**distributed cognition**" this new area that looks for cognitive processes involved in such functional systems. Hence, there is a second corollary shift: from a traditional view of individual's cognition to a socially distributed cognition perspective. According to them, cognition is considered as being distributed across the member of the team and can involve interactions with environmental elements (namely technology). For instance, Hutchins (1995) analysed the cognitive properties of an airline cockpit. He showed that, in an aircraft, there is a distributed cognitive system composed by the two pilots, the instruments, the digital display and the other cockpits artefacts. Hutchins established that the cockpit artefacts can be seen as an extension of the pilot's memory.

The challenge of today's collaborative systems is to overcome the computer limits so as to make participants and their activities visible to one another. This is called **awareness**: **the understanding of the teammates' activities and interactions in the workspace.** Awareness has recently become a new research field particularly for CSCW (Computer Supported Collaborative Work) and CSCL (Computer Supported Collaborative Learning). Being (and also remaining) aware of others is as important in everyday life as in groupware systems. The lack of information about the others in multi—user environment is addressed by providing users with tools that try to "recreate the information landscape of a real-world landscape" (Gutwin & Greenberg, 1999): the awareness tools (from now on called AT in this document). Consequently, the AT are supposed to enable users to offset the lack of social interactions. They also provide a more efficient team collaboration by showing information about presence (is anyone in the workspace?), identity (who is that?), location (where is an individual?), action (what is somebody doing?)…

In the field of Human-Computer Interaction, there have been **relatively few occurrences of research concerning the cognitive evaluation of awareness tools**. Few studies provide data about the use of AT (see Jang, Steinfield & Pfaff, 2002 for example) and the usability issues of AT (Gutwin, Roseman, and Greenberg, 1996; Gutwin & Greenberg, 1998). However, there is a lack of research focusing on the cognitive impacts of AT. **The objective of this thesis is to bridge this gap by examining the effects of the Awareness Tools**. It explores the impact of AT on what is called mutual modelling.

Mutual modelling is the representation and the expectations that an individual construct and maintain of what his/her partner knows, does, believe and intends to do when the pair is performing a collaborative task. **We have investigated whether providing peers with AT can help building more accurate mutual models and being more effective**.

In order to reach that goal, a collaborative video game was employed to conduct experiments. In this game, the two players are involved in a space mission where they have to collect asteroids by sending drones into space. To fulfil this objective, they can use different items and should pay attention to physical settings like gravity, planets, etc. Two kinds of peers were constituted to test our hypotheses. For the first group, we provided them with an AT. For the second, we didn't. We used quantitative and qualitative analysis to gather results from the game and to explore our hypotheses.

Thesis organization

The first two chapters of this thesis present the theoretical framework of the research. It deals with Computer Supported Collaborative Work/Learning, Human-Computer Interaction, psycholinguistics and video games.

Part one defines what we means by collaboration. In particular, it explains the concepts of psycholinguistics and social psychology (grounding and mutual modelling) and the awareness framework.

Part two is a review of how collaboration is supported by computer software. It shows how the issues of grounding and awareness are addressed. This part also contains a quick summary of the awareness tools currently implemented. We finally present the little existing studies concerned by the impact of the AT on different processes (usability, strategy use, etc.).

The next part depicts the statement of our research plan, our hypotheses, the variables, the measures used and the data collected.

In the fourth chapter comes the description of the material and the method : the procedure, the game environment used for the experiments (SpaceMiners) and the population used.

The fifth chapter proposes the results of the experiments and describes the findings of further analysis.

The sixth finally gives an overall conclusion about the main findings as well as critics. We also point out ideas for further research.

1 The process of collaboration

Prior to drawing the implications of Information Technology on collaboration, we present, in this part our theoretical framework. We define what we mean by collaboration, and relates it to psycholinguistics concepts like grounding or mutual modelling, and to the concept of awareness.

1.1 Defining collaboration

Dillenbourg (1999) addresses the issue of defining collaboration. According to him, it can be characterised by focusing on three aspects : the situation, the interactions that occurs and the cognitive mechanisms implied.

Collaboration is a **situation** that involves two or more persons carrying out a joint activity. Dillenbourg identifies three features to characterise a collaborative situation :

- The peers who collaborate have almost the same level considering the action they can perform, the knowledge and the skills they possess. This means that there must be, more or less, a **degree of symmetry in the interactions** performed by the participants of a collaborative activity.
- The participants share **common goals** or a common interest which is the reason of their interaction : performing a task. They also have personal goals (which are their own private motivation).
- There is a **division of labour** among the participants. Academics often distinguish cooperation and collaboration. The author states that “In cooperation, partners split the work, solve sub-tasks individually and then assemble the partial results into the final output. In collaboration, partners work together”.

Collaboration also concerns the **interactions** which take place between the participants. First, a collaborative activity implies **interactivity**. That does not mean that what matters is the amount of interactions. In fact, the extent to which the interactions between group members influence the participants’ cognitive processes is a more accurate criterion to define the degree of interactivity. Dillenbourg also claims that carrying out a joint activity together (*i.e.* to collaborate) implies **synchronous communication** (whereas asynchronous communication is often used for cooperation). As a matter of fact, to work synchronously, participants need to interact synchronously. It must be stressed that **negotiation** is also an important feature during collaboration. Participants discusses, justify, argue and try to convince their partners.

We should finally bear in mind that collaboration imply the same **cognitive mechanisms** as those which operate in individual cognition. Reasoning processes like induction, analogy-based reasoning or self-explanation are used, as well as cognitive load.

Several academics have also stressed that collaboration can be seen as a problem solving task. Roschelle and Teasley (1995) state that:

> *"collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem".*

They also propose the notion of joint problem space to explain what is going on during collaboration:

> *"(...) Social interactions in the context of problem solving activity occur in relation to a* Joint Problem Space *(JPS). The JPS is a shared knowledge structure that supports problem solving activity by integrating (a) goals (b) descriptions of the current problem state, (c) awareness of available problem solving actions, and (d) associations that relate goals, features of the current problem state, and available actions."*

Hence, **collaboration** is a **process of solving a problem and maintaining a shared conception of the situation** (the *JPS*) by integrating information during the task. This understanding of the task is continually shaped and reshaped during the course of the interaction.

Consequently, collaborative problem solving cannot only be seen as sharing tasks. As a matter of fact, collaboration implies interactions between participants, the effort of maintaining a shared understanding of the situation and taking into account the aims and the expectations of the group. The psycholinguistics bases of collaboration are discussed in part 1.3.

Building this shared conception can be carried out by:

- The possibility of introducing new information to the shared representation of the problem.
- The fact that the participants can be aware of the possible divergence of opinion or representations.

- The possibility of “repairing” those divergences of representations.

Therefore, a collaborative technology must provide tools for supporting those functionalities. Unfortunately, computer-mediated collaboration has not kept up with the needs for people to effectively perform collective tasks. Working or playing together in a virtual environment has revealed the tremendous lack of human interactions that occur in co-located activities. That is why distributed teams (of players or workers) create a need for collaboration support. We will tackle this issue in part 2.

1.2 Psycholinguistics framework

Having established and presented what me mean by collaboration, the following part will focus on our conceptual framework : how does it occur. It will present a summary of contributions from the areas of *Psycholinguistics* and *Social Psychology* that are focused on communication processes.

1.2.1 Grounding

As we have seen previously, collaboration consist in building a **shared understanding** of a situation, and individuals that are solving a task together need to have **common grounds.**

This common ground can be defined as the amount of information (understanding, presuppositions, beliefs, knowledge, assumptions…) shared by team-mates involved in a collaborative task. And to be efficient, the partners “need to update their common ground moment by moment” (Clark & Brennan, 1991). The process and effort of constructing and updating the information is named **grounding** (Clark & Schaeffer, 1989). Actually, a common ground may exist at the start of any interaction: having a common culture coming from the membership of a social group, the co-presence of the individuals or the existence of previous interactions (Baker, Hansen, Joiner & Traum, 1999).

Krauss & Fussel (1990) identify three mechanisms by which the common ground is established :

- **Direct knowledge** which is based on shared experiences with individuals.
- **Interactional dynamics** : discussions, grounding evidences (presented in part 1.2.3), shared information, etc.

- **Category membership** : people seem to make assumptions about others' knowledge on the basis of the social categorization they apply to them. One can assume that a cabdriver knows the route to an hotel.

1.2.2 Grounding in conversation

The simplest example of grounding is when people talk. A participant of a conversation must ground what he has said to the audience, that is to say trying to establish if the others have understood his/her utterance (Clark & Brennan, 1991). Moreover, "the contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for the current purpose" (Clark & Schaeffer, 1989). This criterion is named **grounding criterion**.

According to Clark & Schaeffer (1989), a conversation may be divided into two phases:

- The **presentation phase** during which the contributor presents an utterance to his/her partner and waits for a sign of understanding coming from him.
- The **acceptance phase** during which the partner gives evidence to the speaker about what he means. The grounding occurs when the speaker has established that his/her partner has understood him during this acceptance phase.

In a conversation, from the initiation of a contribution to its mutual acceptance, the two partners provide a collaborative effort. To improve the efficiency of the communication, this effort must be minimized. Clark & Brennan (1991) sum this up by the rule of **the least collaborative effort**: "Don't expend any more effort than you need to get your addressees to understand you with as little effort". That's why it is sometimes more efficient to provide an incomplete utterance because the production cost of a complete utterance may be higher than the cost of repairing it.

Thus grounding is the mechanism by which the participants try to establish that their partner has understood what they meant to a criterion sufficient for the current purpose. The notion of grounding is usually employed to study conversations, but it could be extended to the collaboration process.

1.2.3 Grounding evidences

In order to establish if he is understood, the speaker may look at grounding evidence. There can be two kinds of signs: positive evidence (**signs of understanding**) and negative evidence (**signs of misunderstanding**, an irrelevant answer for example). If the addressee shows signs of misunderstanding, the speaker should repair his/her utterance. And if the partner does not show negative evidence, it does not mean that he has clearly understood. Clark & Brennan (1991) identify three forms of positive evidence:

- **Acknowledgements** or back-channel responses: like "yeah, yes, uh uh". The addressee gives a verbal or gestural assessment that he thinks having understood the utterance. Those paralinguistic cues directly affect interpretation : intonation or interjections like "um", "uh" helps the listener.
- When an addressee provide **a relevant answer** to the speaker.

Continued attention: the speaker monitors the activity of his/her partner. Hence, he could see if he's paying attention or not to what he has just said. One way to get a partner's attention is to capture his/her gaze. If the partner did not seem to be mindful, he could assume that his/her utterance was misunderstood.

1.2.4 Estimating other's knowledge

The crux issue tackled by social psychologist is how and individual can estimate the knowledge, the understanding of a situation and the plans of his/her partner on the basis of the perceived information. This issue is addressed by the attribution theory (Heider, 1958).

Attribution theory is concerned by how people explain things to make sense of the world they live in. More specifically, it **focuses on how people try to determine why other persons do what they do**. This theory deals with the information people use in making causal inferences, and with what they do with this information to interpret others' behaviour. Causal attributions is used in order to predict the future behaviour, to anticipate and to control social situations. **Attribution is an underlying mechanism of collaboration, due to its importance in social interactions**. Indeed, collaboration require that partners take one another's perspective into account during the joint activity.

In the original theory (Heider, 1958), the author distinguishes the observers (perceivers who are trying to explain causes of events.), the actors (people whose behaviour is to be explained) and the entities (objects or persons with whom actors are interacting). **Observers form and test informal theories of causes of behaviour on the basis of they perception of the interaction of the actors and the entities**. According to Heider (1958), when an individual offers explanations about why an event happened, he/she can give one of two types. On the one hand, he/she can make an external attribution, that assigns causality to an outside agent or force. Heider calls it **situational attribution**. It implies that an Actor's behaviour is a response to stimuli. On the other hand, he/she can make internal attribution, that assigns causality to factors within the person. Heider calls it **dispositional attribution**. It implies that behaviour was caused by the Actors purposes, beliefs, plans etc. which are affected by (stable) personality characteristics. Heider also claims that observers seems to prefer dispositional explanations over situational causes.

As a matter of fact, the few studies that exists on the attribution processes mainly focuses on estimation of other's knowledge and not on higher level information like plans, intentions or strategies.

The attribution process occurs in three steps: perception of action made by the actor, judgment of intention by the observer, and attribution of causes by the observer. People are good at estimating the knowledge of others in some domains, using relevant information like gender (Fussel and Krauss, 1992) or social category memberships (Krauss and Fussel, 1991) for instance. However, **the judging intentions made by the observers are often biased**. Nickerson et al. (1987) showed that people use their own knowledge as the basis for a default model of what other people know. They found that subjects' estimates of how many students could answer a particular general knowledge question were biased by whether or not they themselves could correctly answer the question. Their study revealed two significant results :

- An individual seem to be more likely to impute information to other people if he/she has it himself than if he/she does not.
- We often overestimate the commonality of our knowledge : people tend to overestimate the likelihood that what they know is also known by others.

Fussel and Krauss (1991, 1992) reached the same conclusion. They investigated the inferences individuals make about what others know. The subjects of their study had to estimate the proportion of the New York City residents who could identify each NY landmark from its picture. They found that subjects were good at estimating the stimulus identifiability but that their estimates were biased in the direction of their own knowledge. It seems that people reason mostly from their own memory or cognitive processes.

Thus little experimental research has examined the attribution processes, even though there is a wide variety of terms that refers to this issue : "perspective-taking" (Krauss and Fussel, 1991), "feeling of another's knowing" (Brennan and Williams, 1995), empathy, inference, etc.

1.2.5 Transactive Memory

The issue of estimating others' knowledge within a group is also tackled by the Transactive Memory Theory proposed by Wegner (1987). This theory examines **the process by which individuals determine who knows what and who knows who knows what**. Wegner claims that transactive memory in a group occurs when each member keeps information on who knows what and develops a sense of the group's areas of expertise. This knowledge is available because of transactions between group members. Thus groups develop transactive memory systems (TMS hereafter) in order to ensure that important information is recalled. A TMS includes information about what the participants know and a shared awareness of who knows what regarding a task.

In this respect, Moreland, Argote and Krishnan (1998) showed that **training the members of groups together, rather than apart, creates stronger transactive memory systems**, which leads in term to better group performance. They trained individuals to assemble transistor radios from 60 separate parts on their own or in three-person groups. About a week later, they found that the groups whose members had trained together recalled more about the assembly procedure and produced better-quality radios than groups whose members had trained separately. Furthermore, they established that group training led to greater specialization by each member in distinct assembly tasks, more fluid coordination of the assembly process, and increased trust among group members in one another's knowledge about radio assembly. The performance benefits of group training are due to stronger transactive memory, not to greater group cohesion or better communication.

In another study, Myaskovsky and Moreland (2000) found that **groups whose members were trained apart (without any communication) performed well after receiving written information about one another's skills**. Their performance was comparable to that of groups whose members were trained together, and both types of groups performed significantly better than did groups whose members were simply trained apart. Transactive memory mediated these effects. Hence, it means that it is possible to build larger TMS by telling people where knowledge and skills can be found.

Wegner (1987) states that Transactive Memory is developed by work group through four different processes :

- expertise recognition : the process where each participant discovers the knowledge and the expertise of his/her partners.
- retrieval coordination : the process through each individual uses his/her perception of who knows what, to find and contact the relevant person in the organization and to retrieve the knowledge needed to complete a task. directory updating : the process by which individuals reevaluate the people they perceive to be experts.

- information allocation : when individuals get new information (a new paper for instance), he/she passed it to the individual who is perceived to possess the most expertise in that area.

In organizations, those processes can be applied through two different approaches : interpersonal approaches (work group contact, news, events and activities) and technological approaches (e-mail, yellow page, intranets). The former cost little, allow access to a wide range of information but can be risky and annoying. The latter can be quick, easy to use but are costly to build and maintain, allow access to a lower range of information and produce only general answers.

1.2.6 Mutual Modelling

After this review of all the theory about estimating other's knowledge or attributing intentions to partners, we can define the concept of **mutual modelling** (from now on called MM) as **the representation that an individual build of his/her partner(s) : knowledge, goals, strategies, understanding of the situation, beliefs and plans**. In essence, MM results form the attribution processes described in the section 1.2.4. Furthermore, MM is more than just transactive memory because it does not only focus on estimating others' knowledge, but also on more "high level" characteristics such as purposes or intentions.

Furthermore, **MM is a dynamic representation**. Indeed, the *initial MM* is modified during the achievement of the collaborative activity by all the events found relevant by the partners : others' interaction with the environment, the artefacts, team-mates, other's reaction to an action undertaken by a partner, etc.

The process of modelling is only carried out up to a certain **degree of precision**. An individual knows what his/her partner knows more or less. And, this degree depends on the task: for instance, landing a plane collaboratively demands a more accurate representation of the other than chatting about holidays.

We have seen previously that the grounding process gathers all the techniques and efforts of building a shared understanding of a joint activity. This could be achieved by two processes :

- modelling : the diagnosis (what an individual knows about his/her partner, having a representation and maintaining it). There is two kinds of reasoning in a situation that involves two persons A and B : A's reasoning about himself et and A's reasoning about B's reasoning.
- interaction : actions, objects' manipulations, verbal interactions, dialogues, repair, preventive repair, etc.

We could also represent the **MM as a continuum defined by three steps according to the level of abstraction of the content : information about the partners' behaviour, information about the partners' knowledge and information about the partner's strategy/values**. The latter one represent people's motivation, their intentions, their objectives and their strategies to accomplish them.

The **physiological bases** of the capacity to understand and manipulate the mental states of other people has been explored by Frith & Frith (1999). This ability, which can be seen in a rudimentary form in great apes, is very well developed in humans. Those authors have found that **this skill depends on a dedicated brain are**a. They reached this conclusion by observing people who have impairments of this mentalizing capacity. Functional imaging studies have revealed the implications of medial prefrontal cortex and posterior superior temporal sulcus. And one of the most striking features is the fact that this brain area is devoted to the detection of motion and the representation of actions. Hence, Frith and Frith conclude that the capacity to understand the other's people activities has evolved from the system that was primarily concerned by the representation of actions.

1.3 Philosophical considerations

David Hume (1740) seems to be the first to underline the importance of common knowledge in social interactions. In his *Treatise of Human Nature*, he argued that a necessary condition for efficient coordinated activity was that participants all know what behaviour to expect from one another. Hume also claimed that without the requisite mutual knowledge, the beneficial social conventions would disappear.

Much later, phenomenologists like Husserl and more particularly his Austrian student Alfred Schultz (1932) stressed the issue of **intersubjectivity**. According to Schultz, the starting point to concerted social action is the observable information available in the situation ; for instance the actions performed by a partner.

The understanding of another person depends on the lived experience of the observer and on the assumptions he can make about what he's perceiving. Schutz calls intersubjectivity the outcome of these assumptions. Heritage (1984), defines it as:

> *"the intersubjective intelligibility of actions ultimately rests on a symmetry between the production of actions on the one hand and their recognition on the other... this symmetry of method is both assumed and achieved by the actors in settings of ordinary social activity" (Heritage, 1984:179)*

Achieving a common experience, a collective action or understanding the world depends on intersubjectivity : it means maintaining a relationship between two people's subjective experience (present and past). Hence, collaborating on a joint activity require a mutual and shared understanding based on the immediate experience of two persons who have only access to their own thoughts.

Thus we can finally state that the process of achieving Schutz's concept of intersubjectivity is a practical attempt to build the common ground.

Besides, several authors have underlined connections between economics and psychology (see, for example, Rabin, 1997). By exploring human reasoning, and cognitive skills, psychological findings can be useful to economic research. That is why different disciplines (mathematics, economics, social science…) are involved in research about the study of human behaviour.

Game Theory is such an approach. The word "game" is used here as a metaphor. It refers to the wide range of human interactions in which the result depends on the strategies of the persons involved. More specifically, Game Theory studies the interaction among players (*i.e.* a metaphor for the decision makers) who are rational to reach their objectives and who need to take into account the decision of the players with whom they interact. It provides a mathematical description of the situation and can be used to make predictions or assumptions about players' behaviour according to the rules of the game. It is used to model economical phenomena like bargaining, bidding in auctions, determining prices…

The equivalent to the psycholinguistics notion of "common ground" is called "common knowledge" in Game Theory. The importance of maintaining this common knowledge in sustaining cooperatives outcomes in strategic situations has also been established (Morris and Shin, 1997) in this discipline. The extent to which it is possible for individuals to approximate this common knowledge for a successful collaboration is a crux issue for Game Theory researchers. They have introduced the concept of *p*-belief. Morris and Shin defines it as "Say that something is *p*-believed if everyone believes it with probability at least *p*".

The problem of giving different initial knowledge to the participants has also been addressed. Indeed, Rubinstein (1989) has modelled the difference between situations where players were not given the same information (common knowledge situation versus almost common knowledge situation).

1.4 A framework of awareness

This part review the theory of awareness developed by Gutwin and Greenberg (1999a). A brief summary of their work is described below to introduce the concept of awareness.

1.4.1 Introduction

When people work together in a shared environment (virtual or not), they need information about the action and the intentions of their teammates. Those information are critical to a successful collaboration, especially in groupware systems (Dourish & Belloti, 1992). This knowledge of others, result of the interaction of the participants and their environment, is named “awareness”. Dourish and Belloti (1992) have given one of the best-known definitions for awareness: “*awareness is an understanding of the activities of others, which provides a context for your own activity*”.

More precisely, Gutwin and Greenberg (1999a) state that **awareness**:

- Is knowledge about a state of the work environment in a limited portion of time and space.
- Provides **knowledge about changes** in that environment.
- Is **maintained by all the interactions** between the team-mates and the environment.
- Is a **part of an activity** (completing a task, working on something…). Maintaining awareness is not the purpose of an activity. Awareness is used to complete a task.

Therefore, awareness is a process that sums up the knowledge extracted from an environment and updates it thanks to the interaction between the participants and their environments.

Greenberg, Gutwin, and Cockburn, (1996) make the distinction between four different types of overlapping awareness (see figure 1):

- **Informal awareness**, that is knowing who is where, whether people are busy and what kind of activity they’re engaged in. Greenberg (1996) thinks that this type of awareness plays a role of “*social glue*” between people.

- **Social awareness**, that is all the general knowledge about the others in a social or conversational context. It can indicate whether a partner is paying attention or being interested.
- **Group-structural awareness**: it is all the information about the composition of the group: status, roles and responsibilities of the others.
- **Workspace awareness:** Gutwin & Greenberg (1999a) define it as “the up-to-the-moment understanding of another person’s interaction with the shared workspace [...] It is awareness of people and how they interact with the workspace, rather than awareness of the workspace itself.

In the remainder of this document, we will focus only on **workspace awareness**. It is also worth to mention that the shared workspace could be virtual or not. It is a place where people work together to complete a task. Thus awareness knowledge is made up of all the elements (perceptual: sound, motion, etc.) that are generated by the interaction of the participants in this workspace.

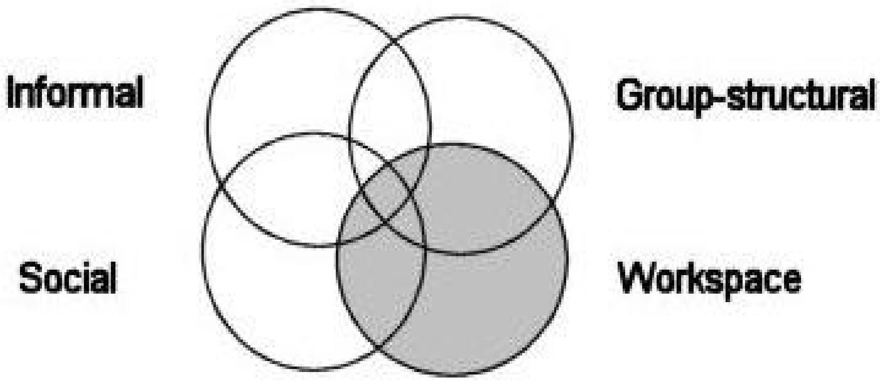


Figure 1 : the four types of awareness (from Greenberg et al., 1996)

1.4.2 Which information is shown ?

According to Gutwin and Greenberg (1999a), elements of workspace awareness can be divided into two parts: those related to the **present** (cf. Table 1) and those related to the **past** (cf. Table 2).

Category	**Element**	**Specific questions**
Who	Presence	Is anyone in the workspace?
	Identity	Who is participating? Who is that?
	Authorship	Who is doing that?
What	Action	What are they doing?
	Intention	What goal is that action part of?
	Artefact	What object are they working on?
Where	Location	Where are they working?
	Gaze	Where are they looking?
	View	Where can they see?
	Reach	Where can they reach?

Table 1 : Elements of workspace awareness relating to the present (from Gutwin & Greenberg, 1999a)

Category	**Element**	**Specific questions**
How	Action history	How did that action happen?
	Artefact history	How did this artefact come to be in this state?
When	Event History	When did that event happen?
Who (past)	Presence history	Who was here, and when?
Where (past)	Location History	Where has a person been?
What (past)	Action history	What has a person been doing?

Table 2 : Elements of workspace awareness relating to the past (from Gutwin & Greenberg, 1999a).

All those elements are a starting point from which individuals can infer their partner's activities, availability, troubles and so on. From Table 1 and 2, it can be seen that the most important awareness information are the elements that answer "who, what, where, when, and how". In a groupware system, all those information are captured and distributed by awareness tools. Thus people can keep track of these things.

1.4.3 How awareness information is gathered ?

In a shared environment, workspace information is gathered thanks to (Gutwin & Greenberg, 1999a):

- Visible activity appears to be an essential flow of information. Auditory sign may also be useful. It can be bodily actions, gestures, the posture of the other person's body in the workspace, the movement of a limb, the sounds in the environment, etc. Those information are the consequence of a non-intentional communication: the producer of the gesture do not move intentionally to inform a partner. This kind of communication is named **consequential communication**. An example given by Norman (1993) relates that, in aircraft cockpits, "when the captain reaches across the cockpit over to the first officers side and lowers the landing-gear lever, the motion is obvious: the first officer can see it even without paying conscious attention. The motion not only controls the landing gear, but just as important, it acts as a natural communication between the two pilots, letting both know the action has been done." (p. 142).

- The manipulation of the workspace artefacts provides visual or acoustic information. For instance, the scratch of a pencil indicates that someone in the environment is writing. This mechanism is named **feedthrough**. It is different from feedback in the sense that this kind of information is not only given to the person who is performing the action, but also to the others who are watching or hearing. Information gathered by an individual provides cues about a modification of an artefact manipulated by a teammate. Hence, it is possible to determine what is being done to an artefact by seeing and hearing changes in the environment.

- The **conversation and the intentional communication** are also significant. Verbal communication is the most important medium to collaborate in a group. The authors distinguish three ways picking up information from conversation: hearing someone's conversation, asking a question like "what are you doing?" and by picking up others' verbal shadowing (commentary people often produce to themselves when they perform a task). For instance, navigation teams on navy ships talk on an open circuit in order that everyone can hear each other's conversations. Therefore, member of the team listen in on these conversations to learn from more experienced partners or to monitor the actions of a junior member.

1.4.4 The use of workspace awareness

Workspace awareness information may be used for a large variety of ways in collaboration. Gutwin & Greenberg (1999a) describe five types of activity aided by the information described in table 1 and 2.

First, workspace awareness can be deployed for the **management of coupling**. Coupling is the degree to which people are working together. The coupling is tight when people see an opportunity to collaborate. It is loose when somebody sees that his/her partner is too busy to interrupt his/her task. By allowing people to know what a team-mate is doing with the appropriate awareness information, they can recognize when the collaboration is possible, when they can confront their work to a partner, etc.

Second, **simplification of communication** is a way to employ awareness information: by simplifying verbal communication and making it more efficient. For instance, in a referential communication, if an individual talk to me about an object that I cannot see, an AT can show what my addressee look could be useful. Consequently, my partner has not to describe or to cite the object; he has just to refer to what is being shown by the AT. It can be a way to overcome the grounding problems (see part 2.2.1) due to the medium.

Third, workspace awareness aids to **coordinate actions** in collaborative activity. By informing partners about where the team-mates are, what they have already done or what they intend to do, it allows people to know when they can collaborate.

Four, the expectations of what is going to be done by the partners can be made thanks to workspace awareness information. **Anticipation and predictions** are based on extrapolating forward from present. By seeing that a partner is catching an object, one can infer that this artefact is going to be used.

Finally, **assisting others** is a way to use workspace awareness. It can be employed to know if a partner needs help and how. Knowing what he has done, where he is and what he intends to do is useful to help him.

Gutwin and Greenberg (1999a) sum up the process by the figure 1. This schema shows how information gathered as we have explained in part 1.5.3 is employed. One of the most striking features is that it is a cycle. As a matter of fact, the use of workspace awareness can be seen as a perception-action cycle. People gather information about their environment, integrate it and use it to perform actions. Consequently, this leads to more efficient collaborative interactions.

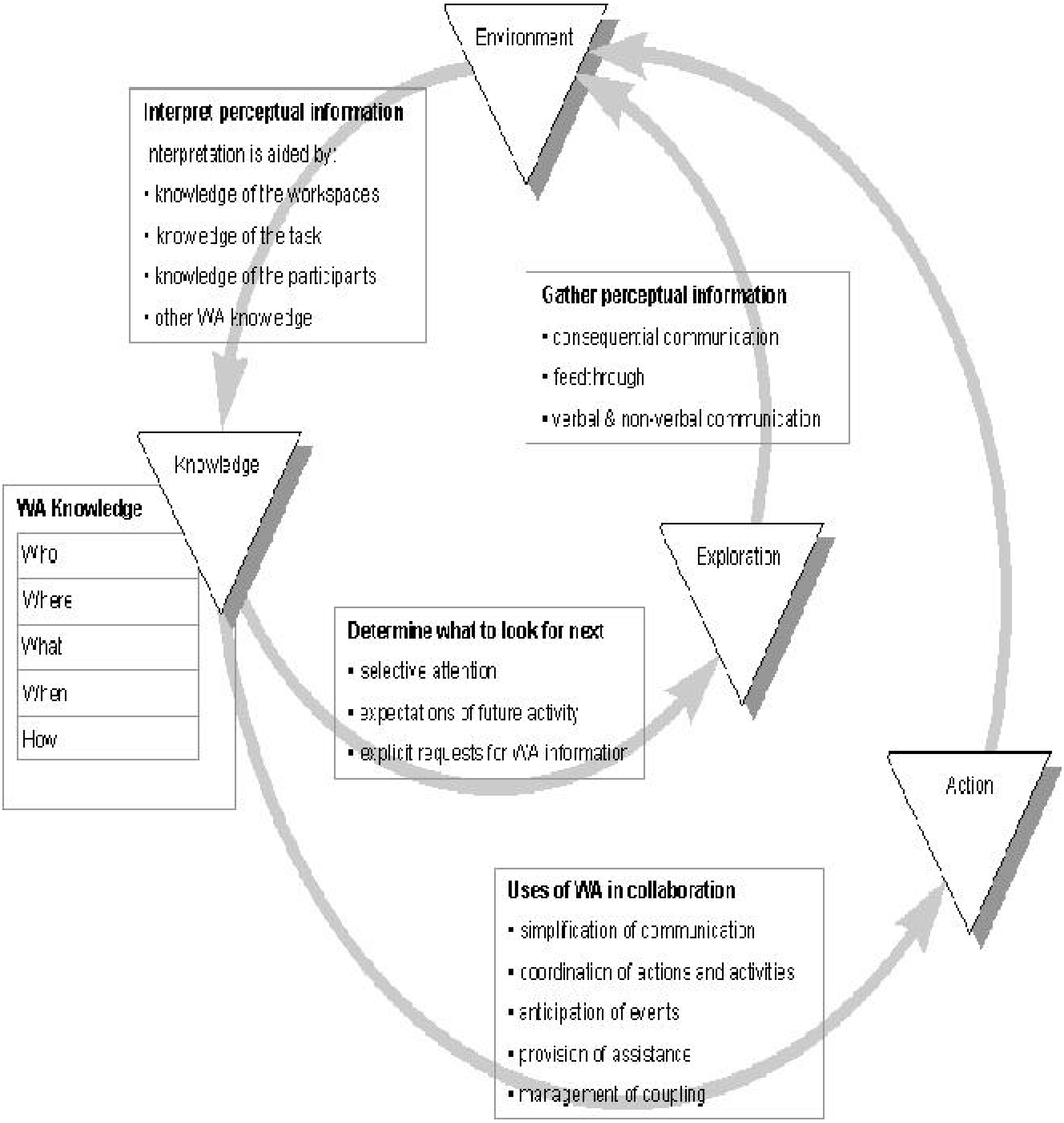


Figure 1 : summary of the workspace awareness framework (taken from Gutwin & Greenberg, 1999a)

2 Computer-supported collaboration

From the preceding sections, we have presented the concept of collaboration in the light of psycholinguistics and social psychology. We now would like to explain how virtual multi-user environments support it. Thus we will move into the field of Human-Computer Interaction (HCI in the remainder of this document).

HCI is the study of how people interact with hardware/software systems and to what extent designers can develop support for successful and adapted interaction with users. In this respect, building a common ground between participants, estimating other partner's knowledge and maintaining awareness of dispersed team-mates are crux issues tackled by this field of research.

We begin by introducing the concept of multi-user environments designed for different purposes: work, learning and enjoyment, that is to say for CSCW, CSCL and video games. We also present multi-users computer games and explains their use as experimental devices to conduct experiments in HCI/psychology. Finally, we addresses the issue of how grounding and awareness are affected by Information Technology

2.1 Multi-user environments

2.1.1 Introduction

Today, people are on the move. Playing, working and learning is mediated by Information Technologies. Thus designers need to tackle the problem of dispersed groups. To meet this need, **groupware systems, learning environments and multi-user video games provide support for collaborative situations that involved dispersed team-mates**. Thanks to those software systems, multiple users located in different places around the world can interact with each other in real-time. These programs also provide users with a shared visual workspace. This virtual space is a place where participants can perceive and manipulate artefacts to perform their tasks. The representation of this virtual space can be three-dimensional like in first-person shooter games (*Half-Life* for instance) or just two-dimensional like in groupware (*Teamwave* for example). That workspace can support the joint activity of medium-sized groups, from 2 to 50 people. And it should be pointed out that participants often shift between individual and shared activities during their work.

Tasks achieved in shared workspaces are mostly generation and execution activities where partners create artefacts, navigate through a space of objects or manipulate existing artefacts (Gutwin and Greenberg, 1999a). The collaborative writing of a newspaper article is a classical example of joint activity undertaken by several geographically-dispersed participants. In this respect, a groupware system can provide them with tools for editing the content, sharing the data and communicating. In this example, users can generate new artefacts (newspaper article) and work on it.

There is **a wide variety of tasks that are carried out in those multi-user environments** : virtual meeting, generating ideas on a whiteboard (brainstorming), planning a task timeline, collaborative text-writing/authoring, collaborative design (in architecture for instance), collaborative learning…

Nowadays, playing is also a collaborative activity, as it is shown in the following part.

2.1.2 Video-games are collaborative devices

One of the first video games was Pong. It was in 1972 and it was a two-users game. Thirty years later, the video-games market has definitely skyrocketed: $8.8 billion dollars in 2000 according to the market analysis company Datamonitor (2000). And multi-user games form a large proportion of this market. As a matter of fact, the emergence of on-line multi-player gaming can be attributed to the Internet. Consequently, **the tremendous growth of this sector shows the dawn of social interactivity in electronic games**. Datamonitor evaluates that the on-line game market will be worth $4.9 billion dollars in 2004 (nearly 33% of the total game market which is estimated at $14.6 billion dollars). Nunamaker (1997) points out that the huge marketplace for multi-player games is a sign of the importance of virtual collaboration.

One of the most striking feature is that game designers talks about “massive multi player games”. Indeed, there are nearly 400,000 players in the persistent virtual world of the role-playing game *Everquest*. Such environments are so big that designers claims that those are not games but medium. Rather than finishing levels or performing missions, the purpose is definitely to make characters live and develop their social relations in the virtual world. At a lower scale, action games like *Counterstrike* allows 20 up to 50 players to compete in teamplay.

Given the number of players, it is to be noticed that support for synchronous collaboration appears much more successful in those multiplayer games than in groupware systems. Several researchers (Ho-Ching et al., 2000) have explored the various techniques to support co-located collaboration in single-display games. In this respect, split screen in MarioKart and AI focus in football games allow to play simultaneously. A previous study (Nova, 2002) has also shown that first person shooter games provide a wide variety of tools to support remote collaboration. It should also not come as a surprise that video games have explored this area much earlier. Many electronic games have developed their own solutions to support team play. The most significant tools are radars, CPU messages, chat, maps, direct communication with headset, etc.

Having established that technical tools exist to support remote collaboration, it is important to digress and provide a brief explanation of the concept of interactions in multi-player games. Nunamaker (1997) describes the interactivity as "the extent to which the user feels convinced of the mutual effect that he or she and the environment have on one another". And according to this claim, the level of interactivity depends on the speed of response, the range of possible players interactions and the mapping of controls. Video Games like Quake or Counterstrike attain a high level of interactivity by providing immediate feedback and pushing input/output devices to their limits. However the interactivity in video games cannot be reduced to user/computer interactions. Indeed, a game-related research, conducted by Manninen (2001) has focused on how the players' teams interact and whether the current video games enable collaborative interactions. This qualitative study has examined Counterstrike players. The findings are drawn from players' interviews and observation. These first-person shooter games allow teams (of 3 to 10 players) to compete in a military tactical combat simulation. Game goals are very simple: defusing a bomb, rescuing hostages, terrorist escape, etc. The study has shown that there was **an incredible range of interactions** observed during the game sessions. For instance, avatar appearance seem to have an importance by providing visual information to other players about the role of the player: if he is a scout or a terrorist, in which team he is playing, etc. Language-based communications in Counterstrike consist of voice-chat messages, predefined keys that can trigger the display of messages, or text-based chat channels. Another kind of interactions supported is the object-based interactions: it consist of the use of weapons, items, ammunitions, armour, health items... Moreover, world modifications are supported by destroying doors or windows. Hence, this study has stressed the existence and the importance of interactions that can support virtual teamplay.

Furthermore, Manninen (2000) has underlined the **strong social aspect in those games**. He has shown that even though multi-players games contain only a small amount of copresence, there is a lot of social actions. From a gaming perspective, teamwork appears definitely to be the cornerstone of success.

Finally, those multi-players video games can be considered as collaborative devices as defined earlier (in part 2.1.1) since they:

- Are real-time software program: every actions performed in the gaming environment is transmitted to the other players in real-time.
- Provide a shared workspace where the players perform their tasks.
- Enable players to carry out various collective tasks and objects manipulation.
- Provide support for small teams of players (from 2 to 50).

2.1.3 Video games used as experimental devices (HCI, cognitive science)

The common perception of video games is that it is a media devoted to children. Electronic games are seen as childish and dangerous by a large amount of people, including academics. Much of the past studies have focused on the fact that they influence children's aggressive behaviour and increase violence (see Anderson, 2000 for instance or Subrahmanyam et al., 2001 for a global review of video games' effects on children). Nevertheless, **few authors have pointed out that video games could be very interesting from a cognitive point of view** (see Greenfield, 1984 for example) **as well as in the field of HCI** (Holmquist, 1997). This thesis would like to complete this idea by showing that multi-players video games can also have an interest in studying the collaboration processes.

Several few academics has stressed the interest of using virtual environments like video games as research tool for psychological investigation (see Slangen de Kort, 2001 for a general review about this topic). Computer games are indeed motivating, fun and achieve enough ease and relaxation for successful experimentation. Maintaining one's undivided attention in video games is certainly easier than in several experimental environments. Another useful aspect is the fact that they attract "participation by individuals across many demographic boundaries such as, age, gender, ethnicity, educational status and even species" (Kowalski, 1997).

However, **there are disadvantages**. As a matter of fact, video games can cause participants to be too excited; and thus it is possible to confound variables such as motivation and individual skill. The validity of such environments is also discussed; there are for instance problems about perception. Indeed, perception in video game is often uni-modal or bi-modal (only the visual and aural senses are stimulated). There is also a gender effect : video-games are often designed for a male audience. And finally the lack of conceptual knowledge in video-games may be a problem as well. Thus we should keep in mind that video games cannot be a substitute for research in the real world.

In the Human Computer Interaction field of research (and in our experiment as well), video games should only be seen as a model of multi-users environment that we can use for addressing the issue of collaboration between team-mates.

2.2 The failure of establishing grounding in Computer-supported collaboration

This part examines the extent to which the grounding process (presented in part 1.2) is affected by the use of Information Technology.

2.2.1 Impact of the medium on grounding

As we stated earlier, grounding is the process of building a common understanding of the situation performed by the participants. It is worth to mention that **grounding changes with the communication medium**. For instance, in a face-to-face conversation, saying « ok » is an easy sign of acknowledgement and grounding. The situation is very different in a chat or a mud (i.e. multi-user dungeon). Indeed, timing precisely an acknowledgement is much more difficult, the «ok » can be understood as an interruption. Clark and Brennan (1991) stress the fact that the acknowledgement cost is higher in the chat case. This is due to the least collaborative effort rule. The effort of making something (producing an utterance, repairing it...) depends on the medium. Thus grounding is affected.

Table 3 shows the **eight constraints imposed on communication by a medium**, described by Clark & Brennan (1991).

Constraints	Definitions	Examples of medium satisfying the constraint
Copresence	Participants A and B share the same physical environment	Face-to-face conversation
Visibility	A and B are visible to each other	Videoconference and face-to-face conversation
Audibility	A and B communicate by speaking	Telephone, Videoconference and face-to-face conversation
Cotemporality	B receives at roughly the same time as A produces	Chat, Telephone, Videoconference and face-to-face conversation but not in e-mail
Simultaneity	A and B can send and receive at once and simultaneoulsy	Chat, Telephone, Videoconference and face-to-face conversation
Sequentiality	A's and B's turns cannot get out of sequence	Chat, Telephone, Videoconference and face-to-face conversation but not in e-mail
Reviewbility	B can review A's message	e-mail and chat but not the others cited above
Revisability	A can revise message from B	e-mail but not the others cited above

Table 3 : constraints on grounding and examples (inspired from Clark and Brennan, 1991).

The fact that todays' team are geographically dispersed leads us to focus on the concept of copresence. It can be defined as a form of human co-location where the participants can see each other. Zhao (2001) claims that it is the condition for having interactions between two people. He has defined a taxonomy of copresence based on the different media used by the participants (see table 4).

Copresence is the cornerstone of collaboration. It is the subjective experience of being together with other participants. Face-to-face communication generates the most intense sense of copresence. Talking in a chat, on the other hand generate a low sense of copresence. As a consequence, creating a strong sense of copresence is the challenging issue that multi-user environments designers need to address.

Where is the other located ? How is the other present ?	**The other is located in physical proximity**	**The other is located in electronic proximity**
The other is present in person	Corporeal copresence (*face-to-face*)	Corporeal telecopresence (*face-to-device*)
The other is present via simulation (AI)	Virtual copresence (*physical simulation, instrumental robots, communicative robots*)	Virtual Telecopresence (*digital simulation, instrumental agents, communicative agents*)

Table 4 : a taxonomy of human copresence in a dyadic situation (from Zhao, 2001)

In this paper, **we will focus on corporeal telecopresence** as it occurred in videoconference or every groupware systems that can provide a communication support. However, in video games, virtual telecopresence is often used. For instance, Quake Bots are a kind of communicative agents who can play with the players and are only artificial intelligences. Thus in multi-users environments, players can frequently face corporeal and virtual telecopresence.

2.2.2 Grounding costs

Among all the media cited previously, they have all a different profile of cost. For instance, producing a message with a chat has a higher cost than with a telephone. Table 5 shows the eleven costs found by Clark and Brennan (1991).

Costs	**Description**	**Cost paid by**
Formulation	How easy is it to decide exactly what to say	Speaker
Production	Articulating or typing the message	Speaker
Reception	Listening to or reading the message, including attention and waiting time	Addressee
Understanding	Interpreting the message in context	Addressee
Start-up	Initiating a conversation, including summoning the other partner's attention	Both
Delay	Making the receiver wait during formulation	Both
Asynchrony	Not being able to tell what is being responded too	Both
Speaker change	Changing speaker	Both
Display	Presenting an object of the discourse	Both
Fault	Producing a mistake	Both
Repair	Repairing a mistake	Both

Table 5 : costs of grounding (inspired from Clark and Brennan, 1991).

Due to the least collaborative effort rule, it can be stated that the participant will chose the grounding technique with the lower cost. The conversation will be influenced by these costs. In a chat, repairing an utterance is so costly that the speaker would rather pay attention to the production of his/her message.

2.2.3 Manifestations of the mutual knowledge problem

Computer-supported collaboration seems to suffer from relationships problems in teams. Cramton (2001) identified five kinds of troubles in dispersed teams using a virtual learning environment:

- **Failure to communicate contextual information** : partners of a team often operate and work in different context; they have difficulty in maintaining information about the context in which their distant team-mates work.
- **Difficulty in communicating the salience of information** : individuals often assume that what is salient to them would be salient to their partners.
- **Unevenly distributed information** : team members do not really know if every partners have the right information.
- **Differences in speed of access to information** : there is a lot of differences in the access and in the use of the multi-user environment. Some partners use it very often (every day) and others not (every three days for instance).
- **Difficulty interpreting the meaning of silence** : silence may be interpreted in very different meaning : “I agree”, “I disagree”, “I have technical problems”, “I am busy with other work”, etc.

The failure to achieve mutual knowledge may have important consequences (Cramton, 2001). If the team members do not share and heed relevant information, the decision quality and the productivity may be affected. Thus there is a greater risk of a decreased decision quality and a poorer productivity in dispersed teams.

The attribution processes (described in part 1.2.4) is tremendously affected by the use of computer-supported collaboration (Cramton, 2001). According to Cramton, people do not have situational information because of the distance between them, because of this uneven distribution of information and this failure to share and maintain information about remote situations and contexts. Consequently, Cramton claims that they tend to make personal attributions : their understanding of others’ behavior focus on the dispositions of their partners.

2.3 Awareness and computer-mediated collaboration

This part exposes how awareness is supported by multi-users environments by introducing the concept of Awareness Tools. It also presents those currently-used tools. We finally review the little studies that focus on examining the impact of computer-supported awareness.

2.3.1 Workspace awareness in real-time multi-user environments

Real-time distributed groupware like shared editors, group drawing programs or multiplayer games allow people who are not in the same place to work together at the same time. These programs provide participants with a shared workspace: a closed environment where the participants can see each other, communicate or manipulate artefacts. In this area, people perform tasks like constructing new artefacts (e.g., architects may draw or design), exploring (finding items), manipulating artefacts, writing texts, etc.

In this kind of environment, there is **a lack of awareness information**. **Workspace Awareness is much more difficult to maintain in virtual environments**: "In face to face interaction, people can generally see the entire physical workspace and all the people in it; in groupware, they have only a small window into the virtual space" (Greenberg, Gutwin and Cockburn, 1996).

Most multi-user environments do not support workspace awareness for three main reasons :

- The interaction between the participants and the virtual workspace generates less information than in a physical one.
- The input and the output of a computer provides much less information than the action in the physical world.
- Groupware systems do not really provide users with the limited awareness information available.

That's why groupware systems provide **Awareness Tools** (hereafter AT) **to overcome these limitations**. AT are much more used to "recreate the conditions and clues that allow people to keep up a sense of a workspace awareness" (Greenberg, Gutwin, and Cockburn, 1996). The little information that is left by the participants is gathered, arranged and distributed to the group. Thanks to AT, participants can receive information that can answer the questions presented in Table 1 and 2. An example of AT is the radar view: a miniature overview of the workspace that locates the teammates in the virtual environment.

However, providing awareness raises two problems: **privacy violations** and **user disruptions** (Sohlenkamp, 1999). Indeed, when people are involved in a task, he does not want all information about him to be revealed. There must be a balance between making information private and providing useful awareness information. **AT must not violate participants' privacy by showing too many details of other teammates**. But this issue must be tackled in the same way as in real-world collaborative work. According to Sohlenkamp (1999), "systems should rely on the establishing of social protocols and conventions analogous to those used in real-world collaboration". Furthermore, we should bear in mind that AT are not designed to verify participants' productivity.

User disruption is also important since information overload is a growing problem. AT should not provide the user with too much details of others' activities. First, it can distract him from the essential aspects of his/her work. Second, those information can be irrelevant to his/her task. And finally, the presentation of information without any explicit user request can disrupt collaboration. Today's age of information must not lead us to forget that we can only process a limited amount of information.

Hence, designing useful AT is a "trade-off between awareness support on the one side and privacy and disruption aspects on the other side" (Hudson & Smith, 1996, cited in Sohlenkamp, 1999). Erickson and Kellog (2000) speak of a "vital tension between privacy and visibility".

2.3.2 Awareness tools (AT)

Awareness Tools are a technical way to support workspace awareness in virtual multi-user environment, and in particular in groupware system. They can be defined and discriminated by six criteria:

- **Content**: which information is displayed (presence, location, intention, etc.). It answers to the question shown in table 1 and 2.

- **Time Span**: there are two possibilities: acquiring the information about the team-mates or maintaining that information. That leads to the following types:

  - **Synchronous awareness**: to obtain information about the present.
  - **Asynchronous/Longitudinal awareness**: to obtain an historical perspective of the information. It can be a summary of the whole information collected after a period of time (compile function) or a differentiation between recent information and past ones (decay function). This kind of AT is often used for social navigation.

- **Mode:** how the user obtains the information. There are three modes:
  - **Passive**: the information from user A (or from every team-mates) is permanently displayed to user B (or to every one).
  - **Active**: the information is displayed upon request. User A has to activate the AT to obtain information about user B (or the whole team). This information remains displayed until user A deactivates these tools (e.g. with a click).
  - **Reactive**: user A activates something and information is provided to user B (or to the whole team, or to everybody).
- **Recipient** of the information (a team-mate, the team or everybody).
- **Perceptual output:** the information can be visual, a sound, etc.

2.3.3 A brief overview of the most important AT

Having established this classification, the following part present a quick review I made of the existing AT, designed for desktop computers or mobile devices as well.

AT in CSCW

In the following tables, I quickly present the most important AT used in groupware. I have described them according to the classification presented in part 2.3.2 with the references of the authors of the systems. Mostly, all the categories of awareness shown in Tables 1 and 2 are supported. There are true signs of presence, identity, action, gaze, view, location, event history. We can also notice that the perceptual output is mostly visual, even though the audio modality is used in two systems. Much of the tools presented in the following tables are integrated into the desktop, so people are able to stay aware of others as they go about their usual activity, moving from application to application.

Collaborative Environments and purposes	References	Awareness Tools Content	Mode	Perceptual output	Interface description
GROVE (multi-user text editor)	Ellis et al., 1990	Presence, action, authorship and identity	Active	Visual	A window can show other users' text entry
ShrEdit (multi-user text editor)	Dourish and Belloti, 1992	Presence, identity, authorship and gaze	Passive	Visual	A window show the name of the participants. They can also "track" others by seeing another user's view.
ClearBoard (shared whiteboard)	Ishii and Kobayashi, 1992	Presence and gaze	Passive	Visual	The system allows two users to collaborate on a shared virtual whiteboard while maintaining gaze

					awareness of the other user (provided in a window). Partners can follow the eye movements of their colleagues
GAZE Groupware System (virtual meeting room)	Vertegaal et al., 1998	Presence and gaze	Passive	Visual	In multiparty video mediated communication, GAZE convey information about the gaze directions of the users in a window.
GroupDesign (multi-user drawing tool)	Karsenty et al., 1993	Presence and view (WYSIWIS)	Active	Visual	The system provide an explicit representation of another partner's view in a window.
Radar view	Gutwin et al., 1996	Presence, authorship and view (WYSISIS)	Active	Visual	The radar view is an overview of the entire workspace (e.g. a collaboratively written document). It shows each participant's view outline and telepointer in a unique colour. Names and portraits are attached to the view rectangle (this rectangle shows what the partner is currently looking at on the document).
Multi-users scrollbars	Roseman and Greenberg, 1996a	Presence, authorship and view (WYSISIS) and location	Active	Visual	It shows each person's relative location (size and position) in the workspace in a unique colour.
Telepointers	Roseman and Greenberg, 1996a	Presence, authorship and View (WYSISIS) and location	Passive	Visual	Telepointers allow people to see each other's mouse cursor motion when team-mates are on he main view (the collaboratively written document for instance)
ARKola	Gaver et al., 1991	Presence, authorship action and location	Passive	Audio	ARKola provide awareness of background activities through audio cues. Sounds indicates distance and location of activity by changes in volume and directions.
TeamRooms (virtual rooms)	Roseman and Greenberg, 1996b	Presence, authorship, identity and location	Active	Visual	Indications of participants' location are provided in a separate display (a participant list with their current location)
Fisheye view (in desktop conferencing system)	Greenberg et al., 1996	Presence, authorship, location, action and identity	Active	Visual	The fisheye view shows both global context and local detail within a single window. It shows the positions and the actions of

					the participants.
Piazza (awareness support)	Isaacs et al., 1996	Presence, authorship , identity and action	Active	Visual	The "gallery" enable people to stay aware of and easily contact a pre-selected group of people with whom they work more closely. The "people browser allow partners to get information about or contact anyone else in the community. And the "glance" component enables people to make audio-video connections to others they see in Gallery, or the People Browser.
Hubbub (instant messager)	Isaacs et al., 2002	Presence, authorship, identity and activity	Active	Visual and audio	Each time a partner becomes active after being idle or offline, a sound plays indicating that someone became active, followed by that partner's Sound ID, so that people can tell who became active without looking. The is also an "activity meter," indicating each partner's level of activity within the last 15 seconds.
Portholes (group awareness tool)	Dourish and Bly, 1992	Presence, identity, action, gaze.	Active	Visual	c Those snapshots are captured in various locations (offices, public spaces) and are augmented with textual information. NYNEX Portholes adopt a similar approach (Girgensohn & Schlueter, 1997)
Peephole (group awareness tool)	Greenberg, 1996	Presence, identity and action.	Active	Visual	Instead of using snapshots as in Portholes, peeholes use icons indicators that show the availability of people in a virtual community.
AROMA	Pedersen, 1998	Presence, identity and activity	Active	Visual	The information gathered by sensors (sound level, user identification) is abstracted and communicated in a window. A symbolic representation of the people presence and activity is provided. AmbientROOM proposes a similar approach (Ishii et al, 1998)
Groupweb (collaborative web brower)	Greenberg and Roseman,	Presence, identity, view(WYSI	Active	Visual	Groupweb enable users to control the browsers of others, to know what they

	1996	WIS) and action.			are doing and where they are looking at. GroupScape (Graham, 1997) allow a similar approach. It could be used for on-line banking (Kobayashi et al., 1998) or for distributed teaching (Souya et al., 1998).

Table 6 : a brief review of synchronous awareness tools.

Collaborative Environments and purposes	**References**	**Awareness Tools Content**	**Mode**	**Perceptual output**	**Interface description**
Quilt (collaborative authoring system)	Fish et al., 1988	Action history and identity	Passive	Visual	A hypermedia system representing the document collaboratively written along with annotations and audit trail recording : it allows collaborators to review each others' activities.
PREP (collaborative authoring system)	Neuwirth et al. 1990	Action history and identity	Passive	Visual	Annotations like in Quilt shows others' activities.
History radar view	Gutwin et al., 1996	View history (WYSISIS)	Active	Visual	The history radar view shows awareness of other's past location (e.g. where the partners have worked on the document). A window shows the part of the workspace already visited by others.
TeamSCOPE (groupware)	Jang et al., 2002	Action history	Active	Visual	A short window shows who has accessed to any file or folder. A calendar provide a detailed description of the events. There is also a system log of all activities in the team's virtual space.
ContactMap	Nardi et al. 2002	Identity	Active	Visual	ContactMap presents to the user a visual model of their personal social networks. Each contact, represented by a picture and a label, is placed in a spatial position reflecting its relationship with both other contacts and the user.
BSCW (web group workspace)	Bentley et al., 1997	Identity and action history	Active	Visual	A window presents a list of past events.
Livemap (web awareness tool)	Cohen et al., 2000	Action history.	Active	Visual	Livemap provides awareness support by showing annotated sitemaps that

					represents website activity. It enables users to know which partner has visited a webpage. It allows a kind of social navigation.

Table 7 : a brief review of asynchronous awareness tools.

Awareness Tools in video-games

A previous work (Nova, 2002) has focused on the AT used in first-person shooter games (like Counterstrike or Quake III). In those games, the workspace is a restricted arena in which players performs various collaborative tasks (capturing a flag, rescuing hostages…). AT are designed to enable communication and collaboration between players. Being and staying aware of other players is a crux issue.

The AT reviewed can be divided as follow :

- *Direct AT* : no tools in the physical sense, basically information remains visual and auditive which bring perceptual clues to the players (weapon noise, footstep noise, etc.).
- *Indirect AT* : like a radar-map (players' location and identity, weapon used), cpu messages (that sums up all recent events), tags (by pointing a player, one can get information about him), scripts (allow players to configure their own AT).
- *Communication AT* : team chat (only with team-mates), chat (with all players), direct communication.

Perhaps the most interesting AT provided by first-person shooter games are the scripts which enable players to configure their own AT. For instance in Quake III, the players can bind keys into an autoexec file. With the following line :

```
bind x say_team "defending %L %W %H – I need you help !"
```

(%L gives current location, %W gives current weapon etc), by hitting the « x » key, the player will trigger on his screen (and on his/her team-mates' screens) the display of the following message : "defending at red flag with rocket launcher and 45% health – I need your help !"

This study has shown that gamers manage to work together without the regular body language vocabulary. Virtual Environment bring them substitute tools to perform their tasks. In this way, first-person-shooter games provide a wide variety of tools to maintain workspace awareness.

Those tools do not support all kind of awareness but mostly presence, identity, location, action, action history and used artefact.

Mobile devices and awareness

Since mobile computing is a new trend in HCI, providing awareness support through Information Technology is a new challenging issue. The term mobile devices refers especially to beepers, mobile phone and PDA, and laptop computers. In essence, the AT cited previously are developed for activities during which participants are assumed to be stationary. **The need for awareness support increases as people leave their desk and still need to collaborate**.

As a matter of fact, research about mobile devices has above all focused on three kinds of awareness :

- **group awareness of presence** : It concerns the group member's mutual awareness of each other's presence. Holmquist et al. (1999) calls IPAD (Inter-Personal Awareness Device) the devices that can support this kind of awareness. They have constructed a prototype, named *Hummingbird*. This device gives participants of a team continuous aural and visual indication when other team-mates are close. The ConNexus prototype (Tang et al., 2001) also enable partners of a group to obtain awareness cues to help them find opportune times to have interactions.
- **context-awareness**: Ljungstrand (2001) has established that mobile phone users communicate more information context to each other than stationary phone users. He then proposed that they should receive context information regarding the person they are trying to reach prior to establishing the call. The purpose is to make phone calls less disruptive.
- **awareness of past experience/activities** : Watanabe et al. (2000). Has developed an i-mode prototype that allow Japanese mobile phone users to write about the events they have experienced, or their feelings by sending text messages from their phones. Each user can browse the awareness memos of others with his/her or her web-browser-equipped mobile phone. The goal is "to assist and maintain relations among friends".

The mobile AT cited previously are just research prototype. Nevertheless, there are commercial AT products, and few were very successful:

- **ActiveBadge** (Harter and Hopper, 1994) : this device indicates the physical location of people and artefacts using an infrared transmitter that emits a short signal. It is employed to aid telephone receptionists in order to locate people and redirect calls to another location.

- **Lovegetty** : this little device beep and flash when it is close to another Lovegetty with a matching configuration. Each user can set his/her own configuration between “talk”, “karaoke” and “get2”. It was compared as a “matchmaker” between two persons, use to create one-to-one relations.

Finally, we should also bear in mind that the use of AT cannot be limited to traditional desktop computer software. Indeed, there are lots of situations where AT are employed : Air Traffic Control (ATC), urban transport control rooms, news rooms, City trading rooms…

2.3.4 AT impact : examining the existing

As we have already mentioned in our introduction, there is relatively few occurrences of research concerning the impact of the awareness tools. **Lots of papers detail the design of cutting edge AT but relatively little studies discusses their relevance, their effects on the task performance or their collaborative/cognitive impact**. It seems that much of the HCI literature is more technology-oriented than user-oriented.

Nevertheless, **few academics examined the usability of the awareness widgets** they propose (Gutwin et al., 1996; Gutwin and Greenberg, 1999b; Isaacs et al., 1996 ; Isaacs et al., 2002 ; Jang et al., 2002). They often use qualitative analysis techniques (observations, interviews, questionnaires) and few quantitative evaluations (measures of the real use). As a consequence, a lot of those studies provide **only subjective insights** about the AT. The following parts present the issues those authors addressed.

GroupLab work on AT usability

Gutwin et al. (1996) focused on three issues that underlie the usability of awareness tools: **the amount and the type of use, the ease of interpreting information and the extent to which AT affects the task completion**.

By using qualitative techniques (observation, self-report and interview), they gathered information about the AT used. In their study, nine pairs worked at workstation separated by a divider. Thus they could see neither the other person nor the other monitor. Participants could only talk across the divider. They used a shared workspace built by GroupLab. This system simulated a newspaper spread. The task proposed was a construction task : participants constructed a page layout from columns, pictures and headlines by moving and dragging objects. In addition to this main view, various configuration of the system proposed awareness tools :

- A miniature view that shows the entire workspace in miniature.
- A radar view that shows the entire workspace in miniature plus each user's telepointer and a view rectangle.
- A « what you see is what I do » (wysiwid) view that shows a full-size but limited area around the other user's cursor.
- A telepointer that shows the position of the other user's mouse cursor in the main view.
- Multi-user scrollbars that show relative positions of the participants as coloured bar beside a normal scrollbar.

They found that **people really tried and used the awareness widgets** they provided in their groupware. Although few participants gathered awareness information by asking their partner about where they were and what they were doing, others watched them work thanks to the AT. The participants seemed to be interested in them and expressed their preference for several tools against others they found useless. For instance, the wysiwid display was nevers used, whereas the radars were the most used AT. Participants reported that they used the AT in order to understand their partner's activities.

They also found **a difference between the ease of interpretation of the various AT** they provided in their groupware. For example, in the context of their task, the radar view and the mini view were easier to interpret than scrollbars. In this study, the main problem for the users was to determine the authorship of the actions. They found difficult to identify where were their partner because the team-mate's movement in the wysiwid display was very jerky. The authors mentioned that since there were only two people in the shared workspace, the interpretation was certainly easier.

Concerning, the extent to which AT affects the task completion, in this experiment, participants claimed that **they were not distracted by the AT**. They reported that they were easily able to switch their focus between the workspace and the awareness tools. Since this result is only a subjective impression given by the participants, GroupLab's member decided to explore this issue in a different way.

In another study, Gutwin and Greenberg (1999b) compared people's performance in two groups of pairs. The first group of participants used simple groupware system and the other used an awareness-enhanced system. In both systems, the medium-sized visual workspace allow people to collaborate by creating, manipulating and organizing artefacts. The participants were given a pipeline construction kit. Each pair had to assembly and manipulate simple pipeline in a shared two-dimensional workspace. In the first condition, participants did not have any awareness tool. In the second condition, a radar view added on the main view into the top left corner showed the entire workspace in miniature. This AT showed the viewport of the current user and the partner's ; it also shows both mouse cursors. Thus this radar view provided visual indications of the other person's location, the location of his or her cursor, and the motion of objects that he or she moved. Participants had to complete three different tasks : assembly pipe so as to meet another person at a specified location, constructing two identical structures from two existing stockpiles of pipe sections and finally verbally guiding the other partner in order to add specific sections to an existing network. The authors examined five variables : completion time, verbal efficiency (number of words spoken, classified in categories), perception of effort (questionnaire), overall preference (questionnaire) and strategy use.

The authors noticed the following results : the group with AT completed the task more quickly (for task 1 and 3) and more efficiently (with less words spoken). Beside, adding AT to a groupware system seemed to improve people's satisfaction. They interpret the fact that the use of an AT increase the performance by claiming that the radar view allowed visual communication. For instance, workspace locations were easier to describe in the AT conditions since the user could see exactly where his partner's view and telepointer were ; they could also provide relative directions based on the partner's current location. Gutwin and Greenberg also claimed that the AT, by providing continuous feedback (about piece location for example) and feedthrough enables the player to increase their performance.

Moreover, the awareness information enabled participants to use different and more effective strategies to perform the tasks. They recorded the strategy used by partners to indicated locations and to indicates pipelines sections. They also identified strategies subjectively by watching the session videotapes. Participants used a wide range of methods, both verbal and non-verbal for indicating locations and pieces (see table 8). Gutwin and Greenberg noticed differences in strategy use between the two conditions that can be partly attributed to the information available in the two interfaces (simple system and awareness-enhanced system). It seems that pairs in the condition without AT used a wider range of strategies than pairs with AT. Furthermore, the two different groups did not use the same strategy.

Strategy	**Use**	**Description**
Relative-to-you	B	Directions base on the other person's current location : e.g., "up and left from where you are"
Describe-location	B	A description of an object at the location: e.g., "the squiggly-looking thing"
Left-right-top-bottom	B	Rough coordinates system dividing the workspace into four blocks: e.g., "next one is in the top left corner".
Relative-to-previous	B	Directions based on a previously identified location: e.g., "near where we were for the last one".
Map-coordinates 3x3	S	Directions based on a 3-by-3 grid: e.g., "go to 1,2"
Pipe-tracing	S	Directions to follow a line of pipe: e.g., "follow this pipe along to the right, and then it goes up"
Follow-rectangle	AT	One person tracks the other by following his or her view rectangle in the radar
Relative-to-us	B	Directions given when both participants are in the same place: e.g. "now down and a little to the left from here"
Move-piece-to-show	S	One person moves a pipe section to indicate a location through the radar or the overview
1D-relative-and-wait	S	Directions to move up, down, left, or right, after which the person giving directions waits until success is established
Follow my cursor	S	One person follows the other's main view cursor
Describe-piece	B	A description of the next piece to be used: e.g., "it's an elbow section with a medium straight on the end"
Show-by-move	B	The piece is moved back and forth in the storehouse
Show-by-drag	B	The piece is dragged up to the construction area
Show-by-placing	B	The piece is moved to the construction area and placed.

Table 8 : strategies used for directing and indicating (from Gutwin and Greenberg, 1999b). The central column indicates in which condition these strategies were used (AT : awareness tool condition, S : simple condition, without AT and B : both conditions).

This topic has also been tackled by Espinosa et al. (2000). In their experiments, participants (grouped into 20 teams of three people) had to solve a problem by using a computer system designed to help groups solved diagnostic problems. They had to decide how to treat a cancer patient by exploring a set of documents (each with information that may or may not be useful : X-rays, results of blood tests, etc.). Half of the teams were provided with the AT. This awareness widget provides information about which documents have already been explored or denied (a « chronological awareness tool »). Data were collected via two surveys. The first survey was given after participants had worked on the problem for 30 minutes. After completing this first survey, participants were given 30 minutes to work on the problem. Then a second survey was given. The authors studied the solution agreement by team members from the second survey. Like Gutwin and Greenberg (1999b), they found that groups who used AT complete their task quicker than groups who have no AT. But they established that those who didn't use the AT got closer to the correct solution. They conclude by claiming that «although task awareness can be very beneficial to team performance, it may actually be detrimental to the team if the task awareness information provided is not properly matched to the needs of the specific task ». As a matter of fact, in this experiment, using this chronological AT lead people to pay attention to a wide range of information. Even though the AT contributed to a more efficient division of labor, it lead to a cognitive overload. Thus the chronological awareness widget used here did not seem appropriate to the task.

AT&T work on Hubbub

Hubbub (Isaacs et al., 2002) developped by Helen Isaac's team at AT &T labs is a mobile instant messenger (available on Palm). It allows people to stay connected as they move. It provides awareness information among distributed groups by giving cues about presence, authorship, identity and activity. Each time a partner becomes active after being idle or offline, a sound plays indicating that someone became active, followed by that partner's Sound ID, so that people can tell who became active without looking. The is also an "activity meter," indicating each partner's level of activity within the last 15 seconds. Hubbub enable users to meet in opportunistic interactions and then to work over the distance.

The authors studied the use of Hubbub over 5.5 months. The system was given to 28 people working on dispersed locations. They logged all Hubbub activity, the conversations and surveyed users after one week of use and again after two and four months.

Like Gutwin et al. (1996), they have shown that the most important information, according to the users and in the context of their task, were activity and location. Presence was also an important feature since people like the Hubbub sounds. One person, who worked exclusively from home said, « sometimes I just like the sounds, just hearing it. It gives me kind of this state of feeling that there's this group and they're working together and you know things are happening ». Participants used Hubbub to feel more connected to the « dispersed team », that is to say, to develop « a sense of connection with the remote colleagues ». The authors also aimed to test the usability of the Hubbub sound interface. They found that it was a powerful mechanism for providing background awareness (presence, identity and activity of others) which lots of participants appreciated even though it is a bit disruptive.

The influence of awareness information on grounding

Ott & Dillenbourg (2002) examined **if the use of an AT can modify the grounding process**. They hypothesized that spatial awareness supports grounding by providing people with the contextual cues necessary to refer to objects, that is to say, knowing what the teammate is looking at could reduce referential ambiguity. In their experiment, two subjects were required to collaborate in a three-dimensional virtual environment. Their purpose was to solve a simple object-matching task. In this shared environment, users could move around and communicate thanks to a structured communication interface. Participants had to locate a target from amongst nine objects and then reach a consensus with their partner over whether their match was correct. In fact, in the context of this task, collaboration consists in a negotiation : once a user has found the object he believed to be the right one (corresponding to the target), he or she proposed it to his or her partner. The teammate could then accept or reject this proposal. The experiment was a succession of ten sequences. Half of the subject pairs complete the five initial sequences with the AT (a view awareness that provides information about what the team-mates is looking at), and the remaining sequences without. The remaining subjects pairs complete the initial five sequences without the AT and the second half with it.

The authors measured the ambiguity of the referential context by logging and counting the number of distinct objects manipulated before to accept or reject the proposal. Thus the greater the number of those manipulated objects the greater the ambiguity of the situation. They found no differences between sequences with or without the awareness tool. Their hypothesis was hence invalidated, the AT did not facilitate the clarification of the referential context in this experiment.

Others considerations about AT impact

Jang et al. (2002) worked on **the amount and the type of use of an AT on the long-term**. They also stressed the issue of the real use of those awareness features. Unlike, Gutwin and al. (1996), their study lasted 13 weeks. They used TeamSCOPE, a web-based collaborative system. This groupware allows communication and coordination in dispersed engineering design teams. TeamSCOPE, like many groupware offer a shared file space, threaded discussion boards, shared calendars, file annotation, a chat, etc. In terms of awareness support, TeamSCOPE provide the access records of shared objects (such as who read a message and who download a file), an activity summary, a notification of who else in the team is logged in, etc.

TeamSCOPE has been tested on dispersed student engineering design teams.. Teams consisted of four to nine students from two locations (among nine universities involved in the project).

By reviewing system log (that recorded users activities and the use of the AT), they found important variations in the frequency of use of the AT and in the distribution of use among partners within the groups. Their findings revealed that only a minority of users (within a group) employed the AT and their use decreased toward the end of the period. These results can be explained by the fact that teams adopt and use groupware differently depending upon specific contexts. As a matter of fact, factors like the availability of alternative supply of awareness information can influence the use of AT. TeamSCOPE proposes a lot of AT, few could be redundant.

Ljungstrand & Segerstad (2000) explored **the extent to which AT influenced the respondents' activities by focusing on how awareness cues of presence affects written message in instant messaging communication**. This AT, WebWho, is a web-based tool that can allow students to virtually locate one another and communicate via an instant messaging system. The students use WebWho for coordinating social activities and to collaborate on mutual assignements. This tool is also used for playful behavior.

They found that awareness of presence is one factor that can influence message composition. In this study, there were three settings : collocated (students are in the same room), distribued (students are in the same building but located in different lab rooms) and distant (access to WebWho from outside the building). The log analysis revealed that the topics of the messages were different in the three settings. Messages sent between lab rooms (distributed) were more related to social coordination (coordinate lunch or coffee break) or to work (« have you finished exercise 3 ? »). Messages sent within the same room seemed to be more mischevious (like funny comments).

Finally, the **perceived value of the AT** has been explored by few academics. Users of AT often express their belief that those widgets had a positive effect on their work (Gutwin et al., 1996; Isaacs et al., 2002). In the evaluation of the Hubbub system (Isaacs et al., 2002), in which a sound ID plays when a partner become active after being idle or offline, said that she like the sounds because it gave her the impression of "being in a group".

2.3.5 Awareness and privacy issues

The topic of **privacy** has also been stressed in the literature about awareness (Hudson and Smith, 1996). By increasing the capture and the storage of information about group members and their activities, the use of AT raises issues about the preservation of privacy.

The relevance of awareness is being increasingly acknowledged in the field of collaborative work. In every organisations, the need for information about partners is obvious. However, people do no want to communicate indication about where they are or what they are doing. Privacy seems to be a big issue that makes impossible to be accepted in many workplaces, for social reasons. Even though people know that AT are designed in order to foster collaboration, everybody fears that it could be used in unethical ways and could lead to intrusions in privacy. Thus there is an additional constraint when designing AT : preserving people's privacy. As a consequence, AT are often modified. For instance, *Portholes* (Dourish and Bly, 1992) provide an integrative view of one's community through a matrix of still video images. This kind of video AT is perceived by workers as a violation in people's privacy. Consequently, modifications could be used like blurring techiques (one can only see a shadow figure of the partner) or proximity sensors (such that the quality of audio and video that is broadcast depend on how close the person is to the camera).

In the real world, there are similar problems and each culture have established social and behavioral norms to deal with them. Those norms depends on the countries, the kind of organisations and the culture of the organisation. For example, at work, lots of people leave the door of their room opened in order to show if they are available or not. In computer-supported collaboration, maintaining privacy is new and the fact that the information can be stored is critical. The need to establish such behavioral norms is high but very difficult as collaborating over the distance is something new. Thanks to AT, we want to give people more control over their information so they can share it in valuable ways with their partners. As a consequence, AT users should definitely have control over information about themselves.

The little studies that focused on awareness and privacy show few violations. The evaluation of Hubbub made by Isaacs et al. (2002) revealed that none of the managers used the “activity meter” to check the productivity of their employees. But the authors explain there is a side-effect: those AT can be used to make judgements about this topic even though managers do not want to implicitly use AT for this purpose. The use of WebWho (Ljungstrand & Segerstad, 2000) was not perceived as an intrusion of privacy by the students. This tool was used during three years and nobody complained about the fact that his or her presence and location was available on the web. However, those studies are often experiments conducted on university students. In companies, in which there is a lot of competition between teams, people pay much more attention to privacy issues. Perhaps, that is why little studies shows privacy intrusions.

3 Delimitation of scope

This part presents our motivation, the research plan and the variables used.

3.1 Motivation and hypotheses

From the preceding sections, we can notice that there is a lot of AT presentations available in the HCI literature. However, the question of the real impact of these tools on the collaborative processes is often overridden. The aim of the study is hence to **discuss their relevance and their effects on the task performance or their collaborative / cognitive impact**.

Thus **our research question is the effectiveness of the awareness tools on the mutual modelling process**. During joint activities, peers maintain representation of what their partner does, believe, knows and intends to do. Part two has shown that in order to support fruitful interaction between dispersed team-mates, multi-user environments provide AT. Those tools enables users to have information on their peer activities. This should contribute to the mutual modelling (MM) process. However, people need to interpret the information provided by the AT to infer his/her team-mates knowledge, strategies or plans. It is possible that AT augment the workload because more information needs to be processed. Indeed, partners could be less effective if there is no resource available to think about the task.

We hence postulate the following hypotheses:

- H1 : Pairs with awareness tools are more effective than pairs without awareness tools.
- H2 : Pairs with awareness tools build more accurate model than pairs without awareness tools.
- H3 : time improves the mutual modelling accuracy : when partners learn to know each other, the representation of each others' strategies is more accurate.

We can also add for post-hoc analysis:

- H1 – H2 : High performance pairs have more accurate mutual models than low performance pairs.
- H2 – H1 : Pairs with more accurate mutual models are more effective than pairs with less accurate models.

Beyond these hypotheses, this study aims to investigate the impact of AT on social interactions during collaborative problem solving.

3.2 Variables

3.2.1 Independent variable

We manipulate only one variable in this experiment : the presence or the absence of the awareness tool (AT). Thus half of the teams were provided with the AT, the other half were not.

The AT in this experiment represents the view of the partner's camera and its laser pointer. Hence, it conveys information about the location of the partner and where he is currently pointing at. This AT is presented in details in section 4.3. The presence or absence of this awareness tool constitutes the experimental condition of the study.

3.2.2 Dependent variables

We used two dependent variables in order to test our hypotheses : **task performance** and **mutual modelling**.

Concerning task evaluation, we used the pairs' score : player A's score added to player B's score (see 4.3 for a description of the game environment).

Concerning Mutual Modelling (MM), two different questionnaires allowed us to calculate an evaluation the value of MM for a pair. First, during the game and for each of the three levels, players had to answer to two multiple choice questionnaires. Those "in-game" questionnaires (see appendix 2 and 3) asked them about what they are intending to do at the moment (guiding his partner, trying to understand his strategy, trying to establish a common strategy, adjusting a shoot, etc.). Then, the in-game questionnaires asked each player about what he thinks his partner is currently doing (same propositions as the previous questionnaire). This questionnaire allowed us to obtain **an objective MM evaluation**, because the questionnaire referred to a particular moment of the game. Results of those first questionnaires were logged on our server. We compared the first answer of a player (about what A is intending to do) to the answer of his partner to the second question (about what B believes A is doing). Consequently, **our MM evaluation is the model accuracy : the number of common answers to those two questions**. We tried to look if A's prediction of B's answer matches with B's actual answer. We could then calculate three evaluations for each player and for each event for instance : MM1a→b evaluates the accuracy of how A estimates B's intentions during event 1 or MM3b→a evaluates the accuracy of how B estimates A's intentions during event 3.

In level 1, the questionnaires are displayed 5 minutes after the beginning. In level 2 and 3, the questionnaires are displayed after the first time a player dropped a tool in the environment (see 4.3 for a description of the game environment).

Second, after the game, each player had to answer to a paper-based questionnaire individually (see appendix 4). We asked the player whether they could guess what their partner was doing. Thanks to the answers, we could obtain a **subjective evaluation of the accuracy of the mutual modelling**.

The following tables (9 and 10) present our different evaluations of the MM. The evaluations in bold will be used for the quantitative analysis.

MMo1a→b	MMo2a→b	MMo3a→b	MMoa→b = (MMo1a→b + MMo2a→b + MMo3a→b)/3
Objective evaluation of how A estimates B's intentions during event 1	Objective evaluation of how A estimates B's intentions during event 2	Objective evaluation of how A estimates B's intentions during event 3	**Objective evaluation of how A estimates B's intentions during the three events**
MMo1b→a	MMo2b→a	MMo3b→a	MMob→a = (MMo1b→a + MMo2b→a + MMo3b→a)/3
Objective evaluation of how B estimates A's intentions during event 1	Objective evaluation of how B estimates A's intentions during event 2	Objective evaluation of how B estimates A's intentions during event 3	**Objective evaluation of how B estimates A's intentions during the three events**
MMo1 = (MMo1a→b + MMo1b→a)/2	Mmo2 = (MMo2a→b + MMo2b→a)/2	Mmo3 = = (MMo3a→b + MMo3b→a)/2	MMog = (MMo1 + MMo2 + MMo3)/3 = (MMob→a + MMoa→b)/2
Chronological MM evaluation (event 1)	**Chronological MM evaluation (event 2)**	**Chronological MM evaluation (event 3)**	**Global objective MM evaluation for a team**

Table 9 : objective MM evaluations obtained thanks to the in-game questionnaires

MMsa→b Subjective evaluation of how A estimates B's intentions during the whole game
MMsb→a Subjective evaluation of how B estimates A's intentions during the whole game
MMsg = (MMsa→b + MMsb→a)/2 **Global subjective MM evaluation for a team**

Table 10 : subjective MM evaluations obtained thanks to the off-line questionnaire

The paper-based questionnaire also ask the players about how was the collaboration (if a player thought he has done much more things for example, or if there was a division of labour, etc.) and about the game (if the game was annoying or funny).

3.3 Operational hypotheses

The following part presents our operational hypotheses.

We first expect a chronological effect of the MM evaluation during the game. Indeed, the players, which are not familiar with each other at the beginning of the game, know each other better and better. Thus their MM should increase. In sum, ***we expect an increase of the objective MM evaluation: MMo1< MMo2< MMo3***.

Concerning H1, our hypothesis is that pairs with awareness tools build more accurate model than pairs without awareness tools. AT provide players with information on their peer activities and thus contribute to the mutual modelling process. Consequently, we expect two effects :

- Effect of AT on general objective MM **: *the global objective mutual modelling evaluation (MMog) is higher when the players have an awareness tool.*** The MMog is the sum of the objective evaluations of the mutual modelling of a team during the whole game, measured by the in-game questionnaires.
- Effect of AT on general subjective MM **: *the global subjective mutual modelling evaluation (MMsg) is higher when the players have an awareness tool.*** MMsg is the global subjective evaluations of the mutual modelling of a team, measured by the off-line questionnaire.

Regarding H2, our hypothesis is that pairs with awareness tools are more effective than pairs without awareness tools. As a matter of fact, the information brought by the AT can enable players to complete the task more efficiently. In order to evaluate the performance, we use the team score. It is the sum of the two players' scores. Then we expect that ***the team score is higher when players have an awareness tool.***

H3 postulates an effect of time on Mutual Modelling, that is to say, the more the players knows each other, the more it enables us to build an accurate representation of each partner's strategy. As a consequence, **we expect MMo3 to be higher than MMo1.**

Concerning the post-hoc analysis H1 – H2, our hypothesis is that pairs with more accurate mutual models are more effective than pairs with less accurate models. Modelling one's partner's reasoning brings knowledge and enables us to understand the domain more accurately. Hence, if MM increases, the performance should increases as well. We will use the objective global MM evaluation to classify the pairs in two categories : pairs with high MM and pairs with low MM. We also use the team score to evaluate the team performance. We expect that ***pairs with high global objective MM evaluations (MMog) have higher score than pairs pairs with low global objective MM evaluations (MMog).***

Regarding the post-hoc analysis H2 – H1, our hypothesis was that high performance pairs have more accurate mutual models than low performance pairs. We postulate that reasoning about how one's partner understanding of the task allows the players to improve the team performance. We will use the team score to classify the pairs in two categories : pairs with high score and pairs with low score. We use the global objective MM evaluations to evaluate the mutual modelling. ***High score pairs have an higher global objective MM evaluations (MMog) than low score pairs***.

Finally, we would like to test the correlation between the two mutual modelling evaluations (of the two players) : is there a correlation between the objective evaluation of how B estimates A's intentions during the three events (MMob→a) and the objective evaluation of how A estimates B's intentions during the three events (MMoa→b) ? We also want to see if there is a difference in those correlation between the pairs which are provided with an AT and the pairs which are not.

The last correlation we want to test is between the subjective and the objective MM evaluation within a team : is there a correlation between the objective MM evaluation (measured by the in-game questionnaire) and the subjective MM evaluation (measured by the off-line questionnaire) ?

4 Experimental Method

This section describes the methodology used for our experiments, the participants, the game environment, the scenario and the questionnaire used.

4.1 Participants

The study was carried out at the University of Geneva. Participants were recruited in Geneva, including students from the University, as well as some non-students. They ranged in age from 18 to 30 years (median age was 25 years). Forty persons participated in the study. We chose only men, in order to avoid gender bias. All were familiar with video games and computers. Few participants had limited experience with joysticks. None of the participants had previously seen the video-game used in the study.

Experimental subjects consisted of 18 pairs (N=18). These pairs were assigned to one of the experimental conditions forming two groups of 9 pairs. Hence, half of the teams were provided with the awareness tool. Participants were assigned a partner they were not familiar with. The game was played on two computers over the local network. Each player sit in front of a distinct computer located in different rooms. He could not see his partner but he could communicate with him thanks to headphones and a microphone.

4.2 Material

The experiment was run on three personal computers : two for the client interface (located in two different rooms) and a server. The server was used to run the game engine and to log the game as well as the audio communication. CoolEdit was used to record the conversations between the two players. We employed Battlecom to enable players to talk to each other over the local network. We ran a Battlecom server on our server and two Battlecom clients on the clients computers used by the two playe rs.

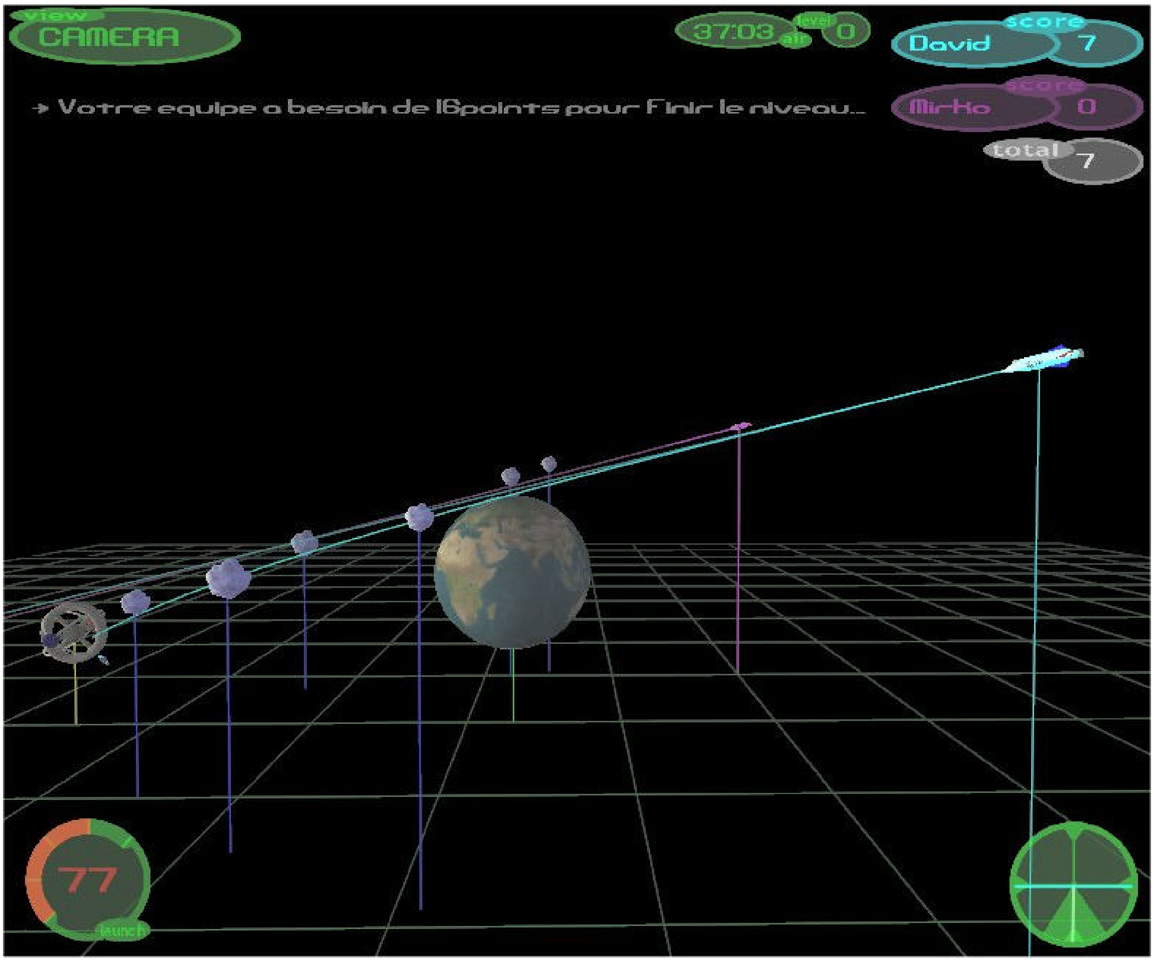
The three computers used were 866 MHz Intel Pentium III systems equipped with 256 MB of RAM and ATI Radeon 8500 (64Mb of RAM) graphic cards. Joypads were Wingman RumblePad, made by Logitech (pictured in appendix 1 with detailed controls). The screens were Hewlett Packard P1100 (20inches). Players could talk to each other by using Plantronics Headsets (microphones and headphones). It is worth to mention that the quality of the audio communication is poor. Player B also hears Player A’s intervention with a short lag.

4.3 The environment : SpaceMiners

SpaceMiners is an experimental platform in the form of a video game for running psychological experiments. It has been developed at the Geneva Interaction Lab (University of Geneva) by Yvan Bourquin, Jeremy Goslin and Thomas Wehrle.

The action is situated in the year 2206, earths resources are exhausted, and the UN has built a network of space stations throughout the solar system to collect the desperately needed minerals and bring them back to earth. **The game involves two players in space missions where they have to launch drones in order to collect asteroids full of minerals and bring them to space stations**.

Screenshot 1 depicts the *Spaceminers* environment. The space is represented by a grid with planets (the brown one), asteroids (in blue), the spacestation (the circles on the left) and the spaceship explorer (which is yellow on this picture). The yellow line shows the trajectory of a launched drone. As one can see on this picture, the direction can be modified by the planet's gravity. **The purpose of the mission represented here is to collect the largest amount of asteroids and to bring them to the space station** on the left. The score represents the number of collected minerals docked to the space stations. The team has a score which is a combination of each player's score. The score is influenced by several factors such as : the drone trajectory (it must go through the center of the asteroid to obtain a good score), the launch speed, the tools positions (that influence the drone trajectory), the number of asteroids in the environment, the planet positions (that modify the gravity and hence the drone trajectory).

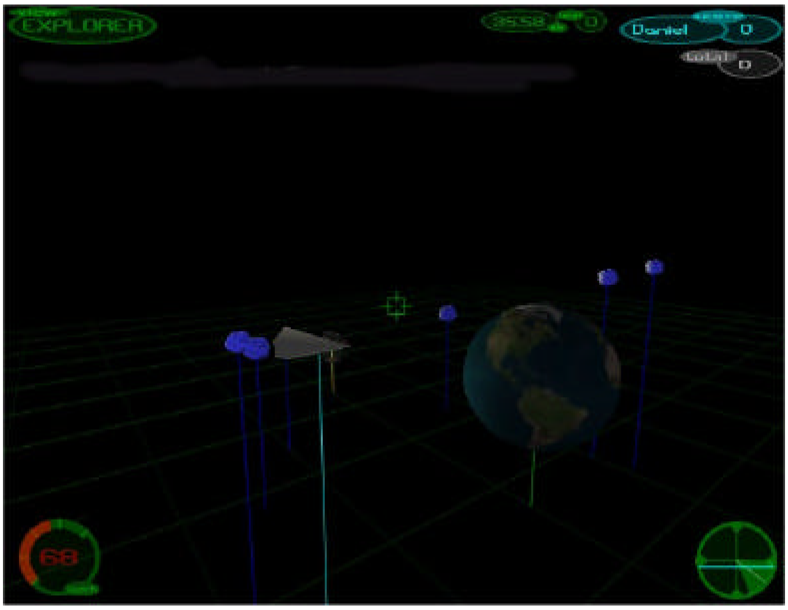


Screenshot 1: the game environment made up of a planet, blue asteroids, two spaceships (blue and purple on the right) and a grey space station. One can see the compass in the lower right-hand corner. The score, the timer and the current level is located in the upper right-hand corner. In the lower left-hand corner, is located the launch speed.. This kind of view can only be seen in the camera mode. Indeed, the spaceship can only be seen by the camera. This screenshot hence depicts the camera view (since we see the spaceship) as indicated in the upper left-hand corner. In this picture, we see that David (the player who controls the blue spaceship) manages to collect asteroids and to dock his drone to the space station. The blue line depicts the trajectory of his drones, passing through the asteroids. Thus he wins 7 points.

The users can play in **two modes** that corresponds to two viewpoints : the explorer mode and the camera mode. They can switch from one mode to another by pressing a key on the joystick. The keys are presented on a reference sheet in the appendix.

In the explorer mode, the position of the spaceship is fixed and players can launch drones that pass through as many asteroids as possible on their way to the space station. This mode can be distinguished from the explorer mode by a green border around the screen; it is also written at the top of the screen. Once the drones are launched players have no control over them. It depends only on the direction of the explorer and the launch speed of the drone. The aim of the player, in the explorer mode, is to control both of these variables in order to plan the trajectory of the drones. To change the orientation of the explorer, players can move a crosshair located in the centre of the screen in the explorer view with the joystick. Moreover, the launch speed can be changed by using the slider on the joystick. In the lower left-hand corner, there is a graphical indication of the launch speed.

In the camera mode, the players can move their camera around in space by moving the joystick. To distinguish this mode from the other, there is no crosshair and no green border around the screen. The camera is very useful to see space from another viewpoint and to place tools in space. Screenshot 2 shows the camera as it can be seen in the explorer mode. Screenshot 1 shows the space and the ship seen by the camera.



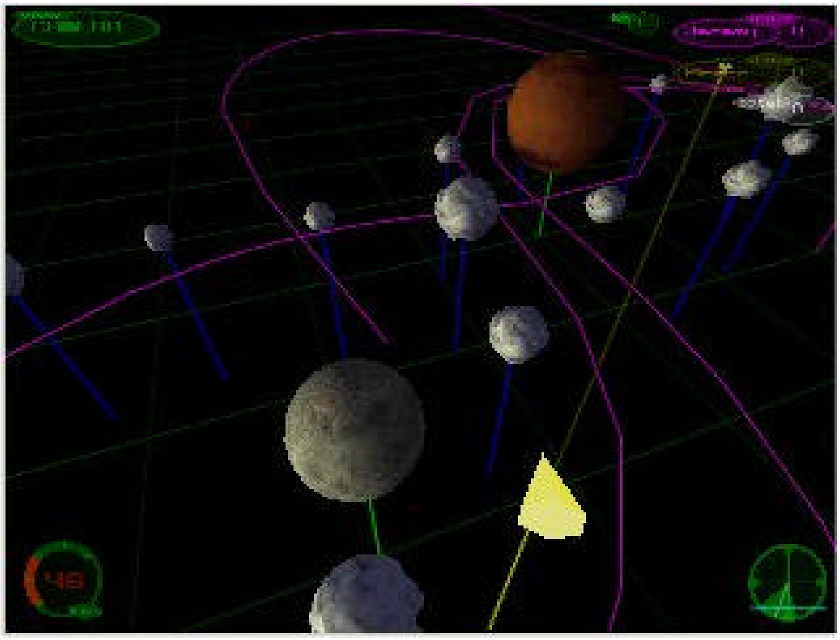
Screenshot 2: view of the camera. This view can only be seen in the explorer mode (from the spaceship). This can convey awareness information as we can see on screenshot 4.

To prevent players from being lost in space the interface shows a compass (in the lower right-hand corner, presented in snapshot 3) to help players to know where they are pointing, the area they can see and whether they are looking up or down. The compass is similar to a normal compass. The yellow line shows you where you are pointing at. The green portion indicates the portion of space you can see. Finally, the blue line shows if you look up (if the line is at the top of the compass) or down (if the line is at the top of the compass).

Screenshot 3 : view of the compass

Finally, there is an indication of the score (of the two players and the team) in the upper right-hand corner. The time-limit and the level are also indicated near the score (on the left).

The awareness tool is the view of the partner's camera and his laser pointer as presented in screenshot 4. By seeing the camera of his partner the player can obtain awareness information about his team-mate location and gaze. The presence or absence of this awareness tool constitutes the experimental condition of the study.

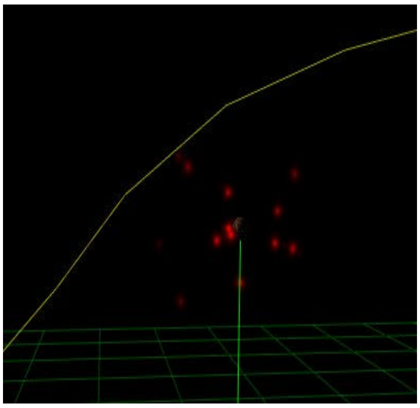


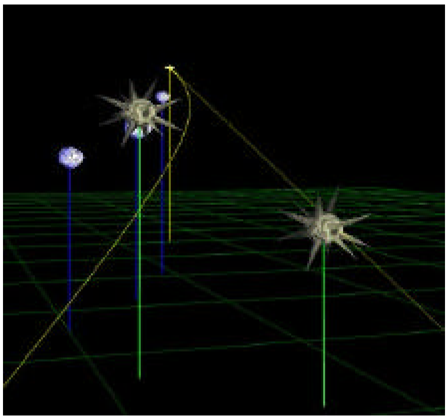
Screenshot 4 : the awareness tool shows where is the camera of a partner. The color indicates that he is currently controlling his camera. The player can also know where his partner is pointing by seeing the direction of the cone.

Screenshot 5 shows the two tools available in the toolbox which is only available in the camera mode. Those tools can modify the drones flight :

- **Blackhole** : it is a small and massive object that has a very high gravitational pull. The blackhole will pull drones towards it.
- **Gates** : they are stabilised entrances to wormholes in spacetime. If a single gate is placed in space a drone will simply fly through it. However, if two are placed in space then a drone that enters one gate will leave the other travelling at the same speed and in the same direction as it entered the first gate. A gate will transfer a drone from one position in space to another instantaneously.

The tools available depends on the level of the game. In level one, players are given no tools. In level two and three, each player has different tools in order to foster collaboration between them. Those tools can be dropped in space or dragged behind the player's camera.





Screenshot 5 : the toolbox and its effects The first tool (the blackhole) pulls the drone toward it. The second tool (the gate) transfer the drone from a position to another.

In the first releases of SpaceMiners, several problems emerged and lead us to modify few aspects of the experiments and the platform:

- **Usability problems** : the subjects found it difficult to use the tools (blackhole and gates). Placing a tool in space was really hard. Players also accidentally removed tool they had placed with difficulties. At this time, there were a third kind of tools : a whitehole (its effect was the opposite of the blackhole effect). The speed sensivity of the pad was too high as well. In order to overcome thoses problems, we chose to put a tutorial which explain the game (goals, background, tools) and provide exercises (about how to navigate, how to place tools, how to shoot, etc.). The speed sensitivity of the launcher was lowered. We removed the whitehole from the toolbox. And finally, a “snap to grid” function was added to place tools more easily in the 3 dimensional environment.
- **Timing problems** : the subjects completed the three levels of the games in three or four hours. We think that it is too long for an experiment, so we put a limit (30minutes per level, so 2 hours for the whole game). The levels were also modified in order to be easier. The difficulty increase from level 1 (no tools) to level 2 and 3 (in which different tools must be used to complete the level).

Although SpaceMiners is a video-game, one should not think the task proposed is simple. Playing is hard work. Spaceminers is difficult for four reasons :

- The **3D perception** is hard, although the game environment uses conventional 3D representations (like VRML scences), few players did not understand the configuration of the world. It could be difficult to perceive the positions of the objects (planets, asteroids, etc.). Two participants (removed for the analysis) were completely lost in space.
- **Ergonomics** : the interface is also kind of difficult to use. At the beginning, the participants could be annoyed by the large number of controls on the pad (see appendix 1). Beside, the matching between the control and the corresponding actions is sometimes hard. For example, few players in the pre-experiments did not manage to move their camera. That’s why we provided them with a tutorial.
- The **task** is hard from a cognitive point of view. Players have to understand the goal of Spaceminers and how to reach it. To collect asteroids, they have to controls lots of factors cited previously (planets, launch speed, drone trajectory, tools, etc.). And factors like tools positioning is hard to understand and to do.
- Even though it is a game, Spaceminers could be very frustrating if the participants are too confused because of the interface (or if they do not understand the task). Affect (like motivation or frustration) has a major impact on how well participants

are able to perform the tasks proposed.s For few participants (and it is very often in experiments), it is a bit boring to play and two hours appears to be very long.

4.4 Procedure and settings

The experiment scenario was divided into six steps :

- A **tutorial** (nearly 30 minutes) explained the aims of the game, the interface, how to move and how to shoot. Each part of the tutorial proposed various exercises to the players in order to learn how to play.
- **Presentation of the game instructions** to the players.
- **Mission 1** (30 minutes maximum) : which can be completed without using any tools.
- **Tools tutorial :** it explains how to use the tools and how to place them in space. Each part of the tutorial proposed various exercises to the players in order to learn how to use the toolbox (how to position tools and how to remove them from space).
- **Mission 2** (30 minutes maximum) : which can be completed by using two gates.
- **Mission 3** (30 minutes maximum) : which can be completed by using two gates and a blackhole.
- **Questionnaire** (nearly 5 minutes) : this questionnaire is reproduced in appendix 4.

Experiment lasted approximately 2 hours and was conducted in French. It took place in two different rooms. Mutual Modelling questionnaires were displayed during missions 1, 2 and three. In level 1, the questionnaires are displayed 5 minutes after the beginning. In level 2 and 3, the questionnaires are displayed after the first time a player dropped a tool in the environment.

5 Results

In the following sections, we report on the results of the analyses performed. We first give an overall feedback about the game environment. Second we report the results regarding each hypotheses. Third, we present further analysis to investigate the effects of the awareness tool on social interactions during collaborative problem solving. We used SPSS to conduct the statistical tests. Most of those tests were conducted at the pair levels of analysis.

5.1 A general feedback about Spaceminers

Most of the pairs (15) played the game during two hours. Only three pairs managed to finish the three levels of the game in less than two hours. The first level was easy for every pairs whereas level 2 and 3 were more difficult because of the need to use tools. Positioning tools was the main problem encountered by most participants.

The off-line questionnaire asked the players whether they enjoyed to play with Spaceminers. Most of them (28 players) answered “amusing” or “very exciting” (5 players). Several participants (2 players) answered it was “ok” and only one found it boring. Overall, it seems that most of the players liked the game Spaceminers and showed different signs of presence, immersion and enjoyment. On the whole, they were all motivated; this could be due to the fact that we selected participants who like to play computer games and were used to play with joysticks.

Furthermore, no major problems occurred during the game. We just cancelled two experiments. The first because one of the player has lost his camera in space during fifteen minutes and the second because of the lack of motivation of the two players (concerning the game and the questionnaires).

5.2 Results for H1 : effect on score

Hypothesis H1 postulates that the awareness tool enables pairs to increase their performance. We want to test the effectiveness of using an AT. We hence expect an improvement of score in the condition « with AT ». The analysis for this first hypothesis was done using one-way analysis of variance (ANOVA). We first comment the descriptive statistics and a boxplot showing the distribution of scores. Afterwards, we provide the results of the ANOVA.

		N	Mean	Std. Deviation	Min	Max
Score	With AT	9	258.67	90.80	127	360
	Without AT'	9	175.67	67.48	51	235
	Total	18			51	360

Table 11 : descriptive statistics

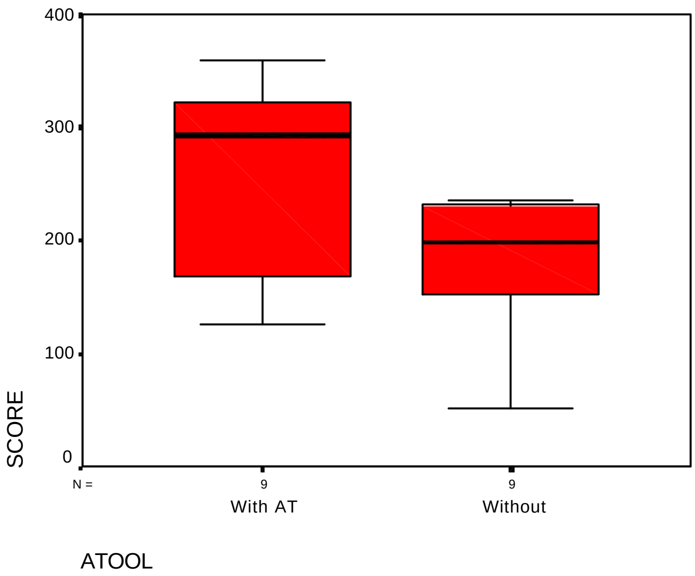


Figure 2 : boxplot showing the distribution of score in the two conditions. The box shows the distribution according to the standard deviation. The black line in the box represents the median. The thin line above and under the red box shows the highest and the lowest scores.

The descriptive statistics shows that the pairs with AT reached higher score than the others. Besides, no pairs without AT reached the mean score of the pairs with AT. It seems that the awareness tool enables players to be more efficient. However, three pairs with AT obtained a lower score than the mean score of the pairs without AT. Furthermore, the standard deviation is higher in the AT condition. The difference concerning the score is indeed more marked in the AT condition. As can be seen on the boxplot, the homogeneity of the score distribution is higher in the condition « without AT». The median also shows that half of the pairs reached score higher than the mean in the two conditions. As a consequence, there is two different populations in each conditions. This will be discussed in more detailed in the next section. We will try to explore what is a « good pair » by carrying post-hoc comparisons.

		Sum of Squares	Df	Mean Square	F	Sig.
Score	Between Groups Within Groups	31000.50 102384.0	1 16	31000.50 6399.00	4.84	.043
	Total	133384.5	17			

Table 12 : ANOVA

Finally, the ANOVA test confirms that there is a significant differences between the two conditions (p = 0.043). Therefore, our first hypothesis is validated : **there is a significant effect of the awareness tool on performance**. In addition, it appears that performing the task without this awareness tool is possible as attested by the score above 200 reached by few pairs in the condition “without AT”.

5.3 Results for H2

Our second hypothesis H2 is that the use of an awareness tool can improve the mutual modelling accuracy of a pair. We operationalized H2 by using MMog (*global objective mutual modelling evaluation)*, as explained in section 3.2. MMog represents the number of common answers to the questionnaires proposed to the two players during the three levels of the game. Hence MMog is the accuracy of the mutual modelling. We expect a difference concerning MMog between the two conditions. We assume that players with awareness tool have more accurate MM, that is to say : MMog (With AT) > MMog (Without AT). The analysis for this second hypothesis was done using one-way analysis of variance (ANOVA). We first comment the descriptive statistics and the distribution of MMog. Afterwards, we provide the results of the ANOVA.

		N	Mean	Std. Deviation	Min	Max
MMog	With AT Without AT'	9 9	1.63 1.58	0.48 0.87	1 0.83	2.67 3.17
	Total	18			0.83	4.5

Table 13 : descriptive statistics

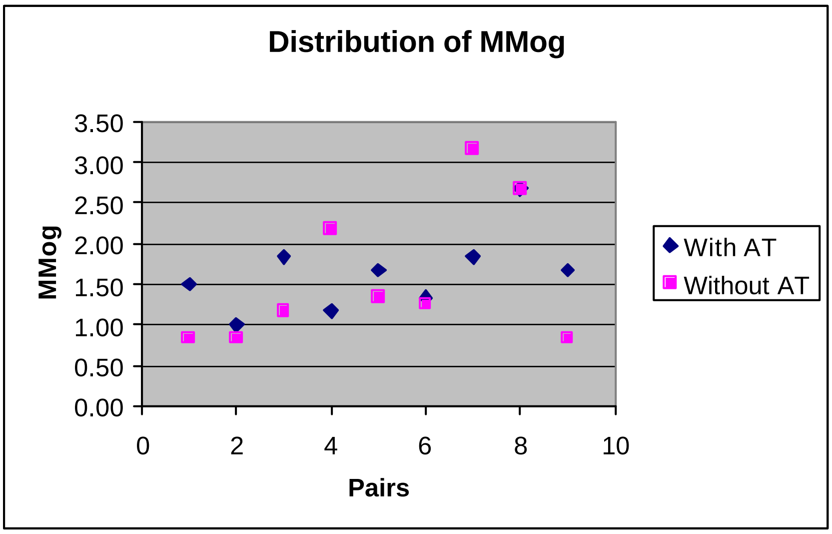


Figure 3 : distribution of the mutual modelling accuracy (MMog) in the two conditions.

Table 13 shows that the MMog means are very close but it is not the case of the standard deviation. As can be seen on the above diagram, there is a difference concerning the homogeneity of the MMog distribution between the two conditions. Unlike the condition "with AT" where the MMog are relatively close to each other, the condition "without AT" is made up of two populations : those who are above 1.5 (high MM) and those who are under 1.5 (low MM). As a matter of fact, in the condition "without AT", two pairs (MMog = 3.17 and MMog = 2.67) tremendously influence the mean.

		Sum of Squares	Df	Mean Square	F	Sig.
MMog	Between Groups Within Groups	9.94^{E}-03 7.97	1 16	9.94^{E}-03 0.5	0.02	.889
	Total	7.972	17			

Table 14 : ANOVA

Thereby, all this goes against our hypothesis and the ANOVA test shows that H2 is invalidated (p = .889). Amazingly**, the use of the AT does not improve the accuracy of the mutual modelling**. **The representation of one's partner strategy is not facilitated by the information conveyed by the awareness tool**.

Presumably, those results lead us to three possible conclusions :

- The awareness tool, by showing informations about the partner's locations and gaze does not improve the accuracy of the mutual modelling. It is also quite possible that showing too much information could lead to a cognitive overload.
- The game (Spaceminers) does not require participants to maintain accurate mutual models, they do not have to care much about each other.
- Our evaluation of mutual modelling is not very precise. Those results does not asses the validity of our instrument measure (i.e. the questionnaires) : it does not allow us to discriminate the pairs with high MM from the pairs with low MM. However, we controlled that the players gave nearly the same number of answers in the multiple-choice questionnaires. Indeed, if one participants answers to all of the questions, he is likely to find the correct answer. And if two partners in a pair answer to all the questions, their MM would be high. But this is not the case; participants gave only two to five answers (chosen between eight propositions for the first level and ten for level 2 and 3).

In essence, our hypothesis H2 is invalidated but the findings call for certain restrictions because of the questionnaire.

We also test the effect of the awareness tool on the subjective evaluation of the accuracy of the mutual modelling : MMs. This variable is obtained as explained in section 3.2 by asking each player within a pair whether they could guess what their partner was doing. We hypothesized an effect of the AT on this subjective evaluation. The one-way analysis of variance (ANOVA) showed no significant effect ($F = 0.26$, $p = 0.618$). Hence, the presence or the absence of the AT has no impact on the way players try to evaluate the representation of their partner's strategy. Anyway, it is hard to take this index (MMs) into account because it concerns the whole game (the questions is asked at the end of the game in the off-line questionnaire).

5.4 Results for H3

Our third hypothesis assume that there is an effect of time and collaboration on mutual modelling. At the beginning of the game, the players are not familiar with each other. We hence postulated that playing together during two hours enables them to improve the accuracy of their mutual modelling. We assume that MMo3 which is the evaluations of the accuracy of the mutual modelling measured in level 3 is higher than MMo1 which is the evaluations of the accuracy of the mutual modelling measured in level 1.

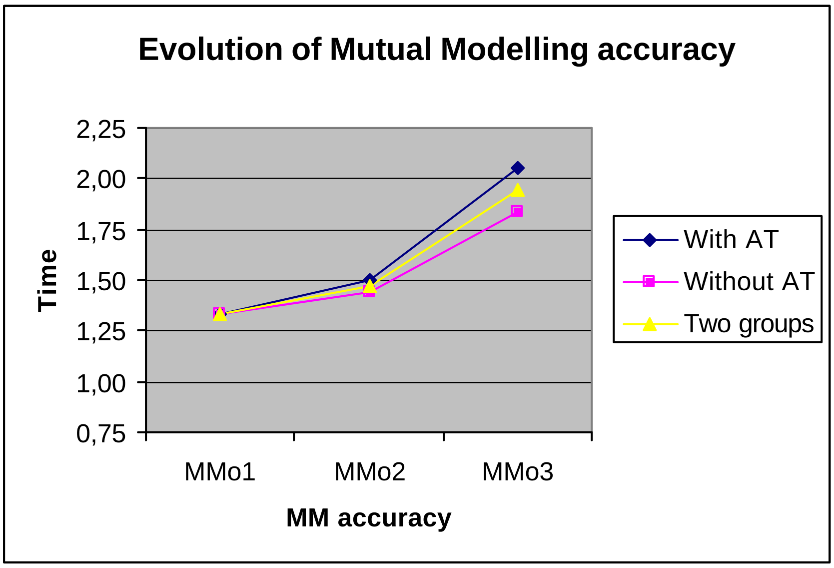


Figure 4 : evolution of the mutual modelling accuracy during the game.

		N	Mean	Std. Deviation	Min	Max
MMo	MMo1	18	1.33	0.84	0	3
	MMo3	18	1.94	1.14	0.5	4
	Total	36			0	4

Table 15 : descriptive statistics

As figure 4 illustrates, the evaluations of the mutual modelling accuracy rises a little between the two first evaluations (MMo1 and MMo2s) and then there is a sudden increase between the two last evaluations (MMo2 and MMo3). As a clue to this phenomenon, we should look at the moment of the evaluation of the mutual modelling accuracy. In fact, the first measure (done with the first questionnaire) appears five minutes after the beginning of level 1. At this time, the players do not know each other very well since they have only played nearly half an hour together and it was just the tutorial. Thus, with the first questionnaire we have just evaluate a kind of baseline for the accuracy of the pairs' mutual modelling. MMo1 represents the evaluations of the two partners' representations of each other's strategies when the player are not very familiar with each other. The questionnaire in level 2 and 3 appears after one of the player drop an object in space. According to the logfiles, this event (and h ence the display of the questionnaire) occurs two or three minutes after the beginning of the level. Consequently, MMo2 (the evaluations of the accuracy of the mutual modelling measured in level 2) represents the MM accuracy just after the tutorial and the first level. By the same token, MMo3 (the evaluations of the accuracy of the mutual modelling measured in level 3) represents the MM accuracy just after the tutorial and level 1 and 2. The implication is that perhaps the players need the tutorial and two levels (nearly one hour and a half) to be familiar with each other. The surge between MMo2 and MMo3 might be due to this phenomenon.

In addition, it should be pointed out that an interaction between the moment of evaluation (MMo1, 2 or 3) and the modelling could occur. After the first questionnaire, players had perhaps paid more attention to their partner in the second MM evaluation as well as in the third. Such a side-effect of the questionnaire is possible and could occur between evaluation 1 and 2 as well as between 2 and 3.

We can also see that we find this general trend in the two conditions (with AT and without). The descriptive statistics shows a slight difference between the means of MMo1 and MMo3. We also notice an important standard deviation for MMo3 : 1.94. The analysis for this third hypothesis was done using two-way analysis of variance (ANOVA). Similar results were obtained using a student test but we just provide two-way ANOVA results here.

	Sum of Squares	Df	Mean Square	F	Sig.
Presence of AT	0.111	1.00	0.111	0.105	0.748
Between Mmo3 and Mmo1	3.361	1.00	3.361	3.189	0.084
Interaction	0.111	1.00	0.111	0.105	0.748
Within groups	33.722	32	1.054		
Total	37.306	35			

Table 16 : ANOVA II

According to the test presented in table 16, concerning the effect of time on the accuracy of mutual modelling, it is only a trend (F = 3.189, p = 0.084) as depicted on figure 4. Therefore, **there seems to be an effect of time but it is not statistically significant**. We reject H3 with p = 0.084. Additionally, there is no effect of the presence of the awareness tool (F = 0.105, p = 0.748). This result is consistent with the invalidation of our second hypothesis. There is also no interaction between time and the presence of the awareness tool (F = 0.105, p= 0.748). As a consequence, this supports the argument that the sudden increase of the accuracy of the mutual modelling is not due to the presence of the awareness tool.

5.5 Additional exploratory results and post-hoc analysis

We conducted further analysis to investigate the effects of the awareness tool on social interactions during collaborative problem solving. We will also try to focus here on a detailed analysis of the collaboration process. We first present the post-hoc comparisons. Afterwards, we report on the results of furthers tests conducted on additional data collected in the off-line questionnaires and in the logfiles such as behavioral data.

5.5.1 Mutual Modelling and performance

Prior to carrying post-hoc analysis, we would like to see on a graph if there is an interaction between the mutual modelling accuracy (i.e. MMMog) and the performance (i.e. score). In figure 5, it is worth noting the difference between the distribution of the two groups. What is clear is that, **in the awareness condition there is no relationship between score and the mutual modelling accuracy**. The distribution is quite random. **Conversely, in teams without the awareness tool, there is a relationship which seems to be linear or curved**. The implication is that **players whose mutual modelling is very accurate reach high scores to a certain degree**. In fact, up to a point (an accuracy of 2.5 on figure 5), the relation is linear. After it is rather curved and there is a plateau.

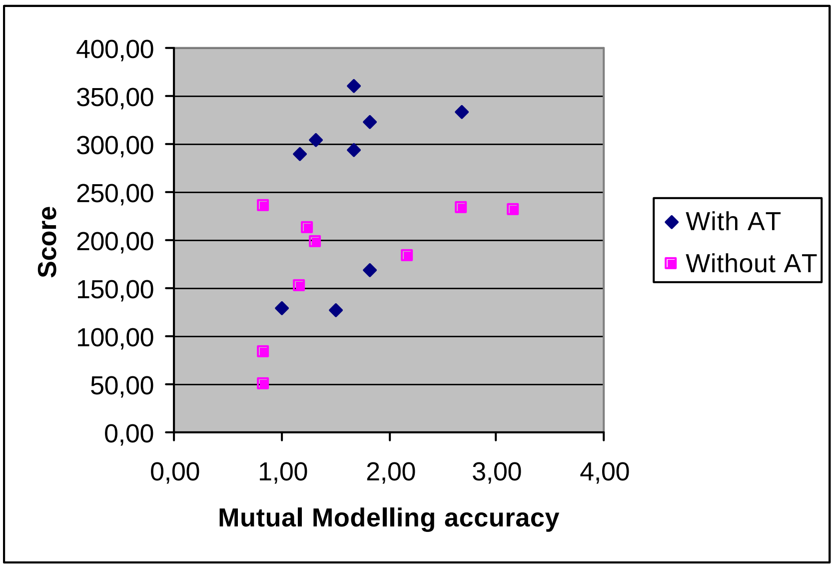


Figure 5 : distribution of score according to the accuracy of the mutual modelling (MMog) in the two conditions (with awareness tool and without).

In order to go further in the analysis of the relationship between score and mutual modelling, we conducted additional statistical tests. On the one hand, we investigated the effect of score on the mutual modelling accuracy. On the other hand, we looked whether there is an effect of the mutual modelling accuracy on score. In those two tests, we used two methods to contrast groups : half split and keeping the seven best value (of score or MMog). From a scientific viewpoint, the findings will call for certain restrictions due to the low number of participants.

5.5.2 Effect of score on Mutual Modelling

As mentioned previously in the section that presented our hypotheses, we postulated that high performance pairs have more accurate mutual models than low performance pairs (H1 – H2). In order to test this hypothesis, we conducted a student test on two contrasted groups. First, we chose a value of score considered to be the average : 200. Next, we built two groups according to this value : high performance pairs (whose score is above 200) and low performance pairs (whose score is below 200). Then we tested the effect of score by looking at their MMog (evaluation of the mutual modelling accuracy) using a student test.

	Score	N	Mean	Std. Deviation	Min	Max
MMog	High	9	1.89	0.78	0.83	3.17
	Low	9	1.32	0.45	0.83	2.17
	Total	18			0.83	3.17

Table 17 : descriptive statistics (half split)

The results of the student test showed no significant effect of score on MMog ($t = 1.88$, $p = 0.078$). There is only a trend. We also conduct the same test with contrast groups by keeping only the seven best players and the seven worst players and there was no significant effect as well. Thus, our hypothesis invalidated : **it seems that high performance teams does not necessarily implied that their mutual models is more accurate than low performance pairs**.

5.5.3 Effect of Mutual Modelling on score

We also expected that pairs with more accurate mutual models are more effective than pairs with less accurate models (H2 – H1). In order to test this hypothesis, we conducted a student test on two contrasted groups. First, we chose a value of the mutual modelling accuracy (represented by the MMog) considered to be the average : 1.33. Next, we built two groups according to this value : pairs with more accurate mutual models (whose MMog is above 1.33) and pairs with less accurate mutual models (whose MMog is below 1.33). Then we tested the effect of the accuracy of the mutual modelling by looking at their score using a student test.

	MMog	N	Mean	Std. Deviation	Min	Max
Score	High	9	250.22	81.25	127	360
	Low	9	184.11	87.25	51	304
	Total	18			51	360

Table 18 : descriptive statistics (half split)

The results of the student test showed no significant effect of score on MMog (t = 1.66, p= 0.116). However when we do not use the same method for contrasting the pairs (if we keep the seven players with more accurate mutual models and the seven players with the less accurate mutual models), there is a significant effect (t = 2.24, p = 0.045). We should bear in mind that some doubts remain as to this finding since the test was conducted on only 14 pairs. Nevertheless, as a consequence, **the probability is that pairs with accurate mutual models seem to reach better performance than pairs with less accurate mutual models**.

5.5.4 Effect of the awareness tool on score and mutual modelling

Furthermore, we also tried to evaluate whether the relation between score and mutual modelling is higher in the pairs with the awareness tool than in the pairs without. We hence conducted 2 two-way analysis of variance on contrasted groups. We chose to only keep the four best pairs and the four worst pairs according to their score for the first test and according to MMog for the second test.

The first test was used to see if there is an interaction between the presence of the awareness tool and the score and if those two variables has an impact on the accuracy of the mutual modelling. The test shows that there is no significant effect, but only a trend of the score on mutual modelling (F = 3.251, p = 0.097). This finding is consistent with the student test presented previously. It also shows no effect of the awareness tool (F = 0.043, p = 0.840) and no interaction between the score and the presence of the awareness tool (F = 0.068, p = .799).

The second test was used to see if there is an interaction between the presence of the awareness tool and the accuracy of the mutual modelling and if those two variables have an impact on the performance. We found that there is a significant effect of the mutual modelling on score (F = 7.523, p = 0.018). There is no effect of the presence of the awareness tool on score (F = 3.547, p = 0.084), it is just a trend. Finally, there is no interaction between the presence of the awareness tool and the accuracy of the mutual modelling (F = 0.223, p = 0.641).

Therefore, these findings shows that **the awareness tool does not enable the high performance pairs or the low performance pairs to improve the accuracy of their mutual models**. The AT just allow them to increase their score.

5.5.5 Correlation between the subjective evaluations and the Mutual Modelling accuracy (MMog)

In order to gain a deeper understanding of how the individuals evaluate the representation of their partner's strategies, we calculated a pearson bivariate correlation coefficient. We checked if there was a correlation between the accuracy of the mutual model for each participant (Mmoa→b which is the objective evaluation of how A estimates B's intentions during the three events) and their subjective evaluation of B's intentions during the whole game (MMs). This subjective evaluation is the result of the second question in the off-line questionnaire. This multiple choice question was « could you guess what your partner is doing ? » and the answers are : not at all, a little, well or very well.

	Pearson correlation between MMs and Mmog of each participant
Player with awareness tool	0.56
Player without awareness tool	0.09
All	0.27

Table 19 : pearson bivariate correlation between MMs and Mmog of each participant in the different conditions

Results in table 19 revealed a relatively small positive correlation (r = 0.27) between the accuracy of the mutual model of each player and their subjective evaluation of their partner's intentions if we do not consider the presence of the awareness tool. The correlation is much bigger for the players with awareness tool (r = 0.56) than for the others (r = 0.09). Thus, it seems that **players in the team with awareness tool are much able to self-estimate their understanding of their partner's strategies**. Those players are much aware of their mutual modelling degree. Perhaps, **the presence of the AT as well as the information it conveys allow them to be more confident in the estimation of their partners's intentions**.

Besides, the fact that the correlations are relatively small raise doubts about the validity of our measure instrument and hence the objective evaluations of the mutual modelling we used in this experiment.

5.5.6 Correlation between Mmoa→b/Mmob→a

We also would like to investigate if there was a pearson bivariate correlation between the objective evaluation of how player A estimates player B's strategies (Mmoa→b, calculated thanks to the results of the in-game questionnaires and compared to B's answers) and the objective evaluation of how player B estimates player A's strategies (Mmob→a, calculated thanks to the results of the in-game questionnaires and compared to A's answers).

	Pearson correlation between MMoa->b/MMob->a
Player with awareness tool	0.24
Player without awareness tool	0.44
All	0.38

Table 20 : pearson bivariate correlation between MMoa→b and MMob→a of each participant in the different conditions.

Results in table 20 revealed a relatively small positive correlation (r = 0.38) between the representation B made about A and the representation A made about B. It implies that **mutual modelling appears to be rather "a personal thing" than an activity carried out by the pair to a certain extent**. As a matter of fact, if the mutual modelling was really based on the quality of the two partners interactions, the correlation would be bigger. And it is not the case, **mutual modelling is hence rather a personal attitude (in the sense that people try to estimate his partner's strategies) than a reflect of the quality of the interaction between the two players in a pair**.

If we consider the presence of the awareness tool, the correlation is amazingly bigger for players who did not use the AT (r = 0.44) than for the others who used it (r = 0.24). Perhaps this result could be explained by the fact that as the players without AT had less information about each other, they were forced to communicate much more and to be more explicit.

5.5.7 Behavioral data

To detail the analysis of the collaboration process, we focused on behavioral data which were stored in the logfiles. It is hence possible to count the number of events performed by players and the whole team. We looked specifically at the number of launched drones, the number of drones docked to the spacestation, the number of tools dragged and dropped into space, and finally the number of view change (spaceship/camera). On average, it appears that those numbers of events are quite similar in the two conditions (with awareness tools and without) as presented in table 21. A student test was also conducted to see if there was a difference. This test showed no significant differences between the two conditions.

	Drones launched	Drones docked	Tool dropped	Tool dragged	View changed
Mean (With AT)	416	70.11	14.44	14.67	384.67
Mean (Without AT)	514.11	75.67	14.67	15.78	317.78
Std Dev. (With AT)	90.80	60.29	5.98	7.14	141
Std Dev. (Without AT)	280.84	57.28	4.47	4.60	176
Sig. (Student test)	**0.48**	**0.84**	**0.93**	**0.70**	**0.39**

Table 21 : number of events for each pair in the two conditions, standard deviation and student test findings.

Thus, there is no difference concerning the actions performed by the pairs. However, if we look closer to the distribution of the view changed, it seems that the mean of view changed in the pairs without AT is highly influenced by a team who changed 656 times. And apart from this team, the players without AT changed their view less than the players in the AT condition. Overall, there is a short difference in the number of view changed if we remove this pair. The mean for the pairs with AT is still 384.67 and the mean for the pairs without the AT is then 275.50. **Players in the awareness tool condition seem to change their view a bit more than players in the other condition, but it just a trend and it is quite logical.**

We also checked that there was no correlation between the number of view changed and the score (r = 0.05) and no correlation between the number of view changed and the accuracy of the mutual modelling as well (r = -0.13).

Now, if we look at the percentage of time spent in each view by the pairs in the two conditions as shown in table 22, we could notice an interesting difference. **Teams in the awareness condition spent more time in the “camera view” than teams in the other condition**. However, the average time spent in the “spaceship view” is similar in the two conditions. A student test showed that the difference concerning the percentage of time spent in the “camera view” is significant (p = 0.03). Since the view of the partner’s camera is the awareness tool, it is not surprising that players in the tool condition spent more time in this mode. By staying in the camera view, they could give information to their partners about their intentions and their locations.

	With awareness tool	Without awareness tool
Average percentage of time spent in the "camera view"	75.41%	62.54%
Average percentage of time spent in the "spaceship view"	24.59%	37.46%

Table 22 : average percentage of time spent in the "camera view" and in the "spaceship view" by the pairs in the two conditions.

A two-way analysis of variance conducted on contrasted groups showed that **pairs in the awareness condition who spent more time in the camera mode did not reach higher score** (F = 1.42, p = 0.26) **than the others.** Nevertheless, the analysis of variance revealed that **pairs in the awareness condition who spent more time in the camera mode reached higher levels of mutual modelling** (F = 8.02, p = 0.015) **than the others**. It implies that there is an effect of the awareness tool on the accuracy of the mutual modelling only for the teams who spent a long time in the camera mode. Therefore, it seems that the information conveyed by the awareness tool could be a benefit for team collaboration. Those information could help players in order to estimate their partner's strategies if the participants understand that they have to make an effort : spending an accurate time in the camera view. The team who did not spend enough time in the camera view had no benefit of the awareness tool.

6 Conclusion

This section finally concludes the dissertation. It summarises and discusses our results, indicates the limits of our experiments and presents the impacts for practitioners. We also propose new ideas for further researches.

6.1 *Summary of our contribution*

We hope this document will contribute to the understanding of the cognitive mechanisms which explain the effectiveness of collaborative work in the context of distributed cognition theories. We explored the field of research concerning the cognitive impacts of the awareness tools used in collaborative multi-user environments. The studies we have presented in this document address two issues : the effect of the awareness tool on performance and the impact on the mutual modelling, e.g. the representation that an individual construct and maintain of what his/her partner knows and intends to do when the pair is performing a collaborative task. So far, most findings confirmed our hypotheses and intuitions. Some results, though seem to be contrary to expectations. The two versions of the Spaceminers' interface differed only in that the awareness tool provided visual indications of the partner's location and his gaze. The statically significant differences between these two similar interfaces suggests the additional awareness information helped players finish the three levels more efficiently. Overall, the findings suggests the benefits of awareness tools on task completion. However, the results concerning the impact on the accuracy of the mutual modelling is not so easy to explain. The impact of the awareness tool on the collaborative processes, namely on mutual modelling, appears to be more complicated.

Figure 6 summarizes the results. As can be seen on this schematic diagram, the performance of a team, measured by their score, could be explained by two things : the awareness and the mutual modelling. Those two characteristics contribute to the collaboration, hence to the joint activity. However, presumably it is not possible to claim that the awareness improves the mutual modelling which improves the performance. The influence of the awareness and the mutual modelling are more intricate.

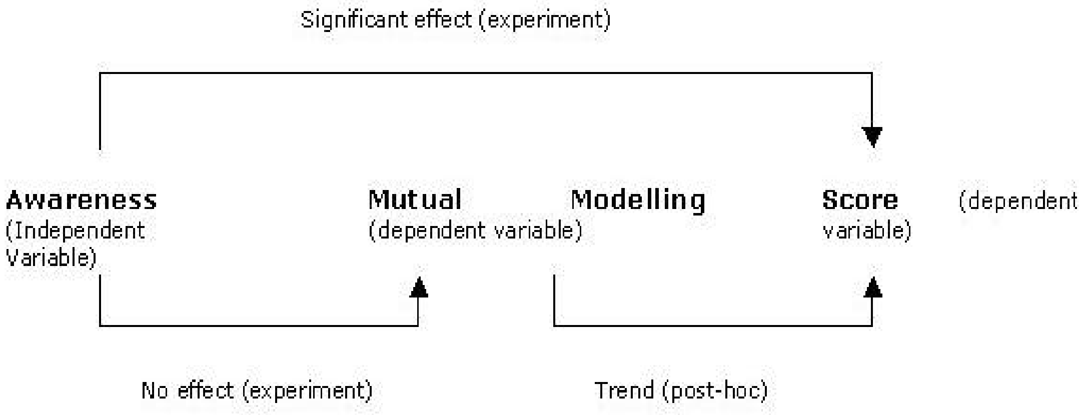


Figure 6 : summary of the results concerning our hypothesis.

Our results are consistent with the literature on awareness. First the fact that teams in the tool condition reach higher score than the others is consistent with the findings of Gutwin et al. (1996) and Espinosa et al. (2000). In their experiment previously described in section 2.3.4, they also found that awareness can be beneficial to team performance. We could explain why the addition of this tool in Spaceminers leads player to reach the highest score. In fact, this tool provide a continuous feedback to the partner who can see where is his team-mate. This could be extremely useful in tasks like object positioning. In such tasks, the division of labor was clear : player A guided player B's movement by giving him instructions about where dropping the object. The feedback provided by the awareness tool is incredibly useful for player A to help player B. Consequently, the information conveyed by the AT helped players to achieve their strategy and thus to be more effective in several tasks. It allowed pairs to complete tasks more easily and more quickly unlike the team in the no-tool condition who faced more troubles (for instance when they had to position tools). Therefore, it was certainly less frustrating for teams in the tool condition. Additionally, the AT provided visual evidences about the player's location. Then it is obvious that those visual indications aided the task by allowing people to avoid describing verbally their location into space. The team is thus more effective because player A had not to describe where he is and player B had not to interpret this description. As suggested by Gutwin et al. (1996), the use of the awareness tool leads to transform a task from a verbal to a visual activity and hence induce a quicker completion of the task.

Furthermore, as we found in the exploratory analysis, the benefit of the awareness tool on mutual modelling is only true for groups who used frequently this tool by spending a large amount of time in the camera view. Espinosa et al. (2000) similarly revealed the same aspect. They go further by claiming that even though awareness can be beneficial to team performance, it may also be detrimental to the team if the tool is not properly matched to the needs of the specific task. Our finding also raises a new question : do players really used the awareness tool ? Indeed, if there is an effect of the tool on mutual modelling only for the players who used it frequently, it may be possible that only a few players in the tool condition noticed the advantage of using it.

It is also worth pointing out that awareness is not the only component that matters concerning grounding or mutual modelling as we explained in the theoretical part of this dissertation. Actually grounding is made up of two components : awareness (i.e. information about the environment, its modifications, the participants and their activities) and the acknowledgement that participants have noticed and understood that something happened. It may be possible that the awareness tool give useful indications for team-mates, but they still have to interpret those cues. Thus for different reasons (misunderstanding or cognitive overload for instance), players are likely to miss this step. It could be a reason why there is no significant effect of the awareness tool on the prediction of the partner's behavior in our study. Indeed, we only focused here on awareness and not on the mutual understanding process as a whole. We did not analyse the verbal interactions, which are very important during collaboration and addtionally could have shown us acknowledgement cues.

It should also be stressed that the awareness tool seems to make players more confident in the estimation of their partner's intentions. We indeed found that players in the team with awareness tool are much able to self-estimate the understanding of their partner's strategies. This seems to be a side-effect of the AT : by providing indications about the partner's activity, the AT gives evidences that help the player to understand what he is intending to do.

Finally, those results also allow us to speculate on the concept of mutual modelling. It appears that estimating one's partner's strategy is rather a personal attitude than a reflect of the quality of the interaction between the two players in a pair. The relatively low correlation between the degree of modelling of each pair member showed us that mutual modelling is in fact not so "mutual". In order to build this "mutual model", people need to make a personal effort : interpreting the actions, the communications and the modifications of the environment so as to understand what the partner is doing.

6.2 Limits

Nonetheless, those results calls for certain restrictions. On the one hand, from a strictly scientific point of view, the number of participants is quite low : eighteen pairs (nine in each conditions). Besides, those participants were university students, which is not a group very representative of the population. Students are actually video games players but groupware systems (or other multi-user environments) are used by a much broader group. On the other hand, we can also have reservations about the instrument. Spaceminers is perhaps too complex and suffer from usability troubles that are difficult to deal with for lots of people. Furthermore, the method used to measure the accuracy of the mutual modelling may be unsuitable. Using a simple questionnaire to measure the accuracy in predicting partners answers is in fact a bit inaccurate and way too subjective. Some doubts remains as we noticed thanks to the statistical analysis. We should use a more objective method to evaluate this variable. A solution would be to analyze of redundancy (i.e. the number of times player A performs an action that player B's previously performed). Additionally, our questions just dealt with information at the behavior level. We should have used indications at the knowledge ("Does you partner understand the gravity concept ?") or strategy level ("Among the following strategies, which one describe the best your partner's strategy ?"). In addition, the fact that we found an effect of the awareness on the mutual modelling only for the players who spent a large amount of time in the camera view shows that it should have been useful to conduct pre-experiments. We should indeed have checked if the players used the awareness tool reasonably often. It is possible that we found no significant effect of the awareness on mutual modelling because few pairs did not used the tool sufficiently. That is also why we should consider re-designing the awareness tool.

We could criticize the tool we used as well. Actually, we considered here the awareness as a simple tool that convey specific information about the participants' behavior. In fact, awareness is not only this kind of "widget", the situation is more intricate. We should reconsider the definition of awareness as a diffuse flow of information : lots of different cues, signs, evidences which are combined. This flow makes sense and it is very difficult to create a tool to enable this combination.

6.3 Impact for practitioners

In addition, this study not only belongs to fundamental research; there are several impacts for practitioners as well, mostly for multi-user environment designers. Even though this experience has no real "ecological" validity, the findings provide evidence that location and gaze awareness can be useful in certain situations. Our findings could help produce recommendations for designers. As we mentioned above, the use of the awareness tool in Spaceminers leads to transform a task from a verbal to a visual activity and hence induce a quicker completion of the task. This a clear lesson for designers : instead of letting participants describing their locations or the artefacts they are talking about, an awareness tool could usefully show those kind of indications. Another interesting lesson is that designers should keep in mind that using an AT is not systematic. As we have seen in our experiment, several players did not really notice the potential of this tool. Thus, designers should provide users with usable AT and teach them their real value.

Nonetheless, it is obvious that Spaceminers do not propose players ecologically valid tasks to perform. Since it is game, the purpose for users is clearly to have fun. Issues like privacy or efficiency cannot be taken into account unlike real work.

6.4 Further analysis

Our further research in this area will move in two directions. First, we will continue work on the data obtained on this series of experiment. We want to look more closely at the differences between the pairs (concerning their score or the accuracy of their mutual modelling). The issue we could address is whether the pairs with awareness tools develop different problem strategies than those without awareness tool. One possible analysis is to look at the activities : whether they are sequencialized and to what extent they are balanced. Balance and synchronization are two key approaches we could explore. For instance, looking whether both player fire drones at the same time, or whether they assigned roles (e.g. one guides, one executes). In order to conduct this qualitative study, it should be relevant to have an indicator that tells us whether the players coordinated their activities. Another possible analysis is to look at the pairs' dialogues to complete our study of mutual understanding, which is, as we stated previously made of two components : awareness and acknowledgement. Second, we may also run a new experiment. In this case, we should reconsider our awareness tool and build something different, not a simple and unique tool but a rather different interface that can show various awareness indications like the partner's view, the view he is using, the position of the tools he is dragging, etc. Work in this direction will also necessitate a new method to measure the accuracy of the participants' mutual models as explained previously. Of course, it may also be interesting to conduct ecologically valid experiments to complete our results. Besides, we focused here on the impact of awareness tools on the cognitive processes. Addressing the social issues about AT could also be an interesting avenue.

In the end, it may be concluded that Spaceminers is an interesting environment that enable us to conduct experiments to study the collaborative processes. We believe that observing and analyzing the players' behavior in this video game can tell us a great deal about collaboration and its socio-cognitive mechanisms. Another challenging issue could also be to examine how awareness of others and mutual modelling is maintained when there is more than two players. This situation clearly exists, especially in computer games like Counterstrike where teams constituted of five to fifteen players faces each other. Those current networked multi-player games shows a strong social aspects. This topic can be tackled from different perspectives by using different approaches like quantitative studies like what we presented here or qualitative analysis such as participant observation and interview techniques. Finally, if we want to look further into the future, we could explore how the new trends in human-computer interaction (e.g. ubiquitous computing, multimodal interaction or mixed reality) could help supporting awareness and mutual modelling.

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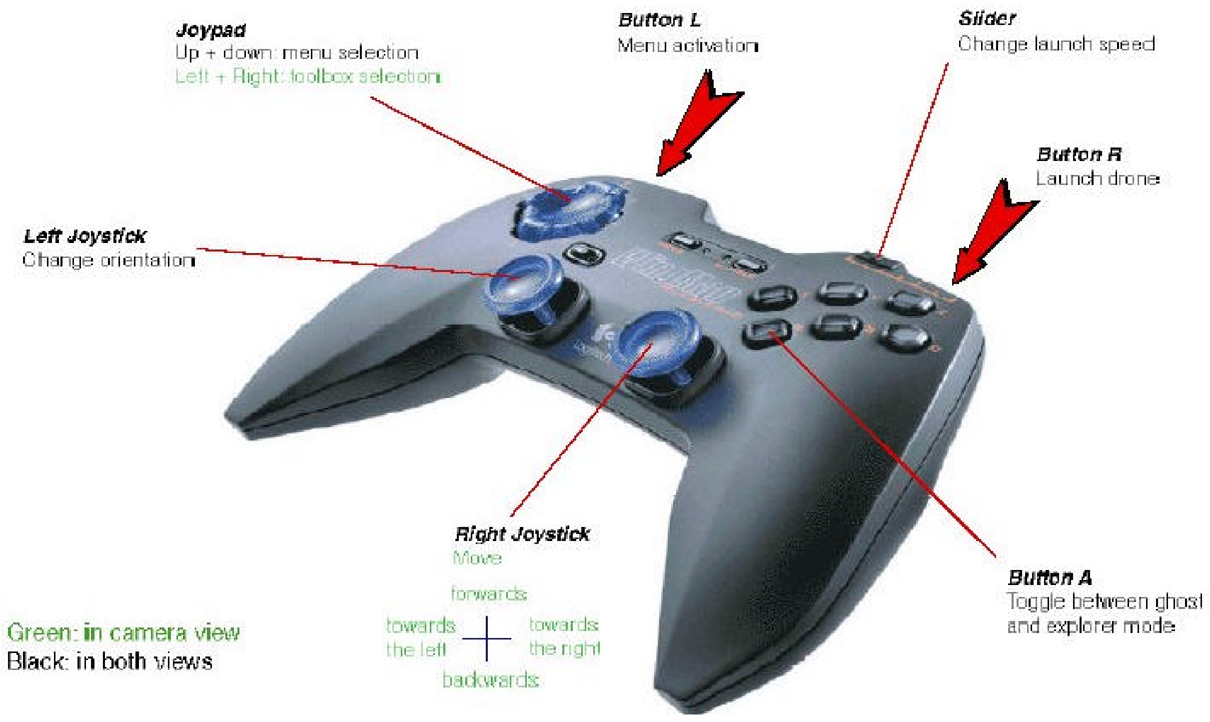
Appendix 1 : Joystick reference sheet



Appendix 2 : in-game questionnaire (1)

This questionnaire is used in level 1

Que cherchez-vous à faire pour le moment ? (*plusieurs réponses autorisées*) ❑ Régler l'angle de tir de mon drône ❑ Régler la vitesse de tir de mon drône ❑ Guider mon partenaire ❑ Comprendre ce que mon partenaire veut faire ❑ Mettre au point une stratégie pour réussir notre mission Comprendre la trajectoire suivie par ❑ mes drônes ❑ les drônes de mon partenaire ❑ Aucune des propositions ci-dessus ne me convient

Que pensez-vous que votre partenaire cherche à faire pour le moment ? (*plusieurs réponses autorisées*) ❑ Régler l'angle de tir de son drône ❑ Régler la vitesse de tir de son drône ❑ Me guider ❑ Comprendre ce que je veux faire ❑ Mettre au point une stratégie pour réussir notre mission Comprendre la trajectoire suivie par ❑ ses drônes ❑ mes drônes ❑ Aucune des propositions ci-dessus ne me convient

Appendix 3 : in-game questionnaire (2)

This questionnaire is used in level 2 and 3

Que cherchez-vous à faire pour le moment ? (*plusieurs réponses autorisées*) ❑ Régler l'angle de tir de mon drône ❑ Régler la vitesse de tir de mon drône ❑ Guider mon partenaire ❑ Comprendre ce que mon partenaire veut faire ❑ Mettre au point une stratégie pour réussir notre mission Comprendre la trajectoire suivie par ❑ mes drônes ❑ les drônes de mon partenaire Positionner un outil pour dévier ❑ mes drônes ❑ les drônes de mon partenaire ❑ Aucune des propositions ci-dessus ne me convient

Que pensez-vous que votre partenaire cherche à faire pour le moment ? (*plusieurs réponses autorisées*) ❑ Régler l'angle de tir de son drône ❑ Régler la vitesse de tir de son drône ❑ Me guider ❑ Comprendre ce que je veux faire ❑ Mettre au point une stratégie pour réussir notre mission Comprendre la trajectoire suivie par ❑ ses drônes ❑ mes drônes Positionner un outil pour dévier ❑ ses drônes ❑ mes drônes ❑ Aucune des propositions ci-dessus ne me convient

Appendix 4 : off-line questionnaire

1. Comment s'est déroulée la collaboration ?

J'ai tout fait	J'ai fait plus que lui/elle	Le travail a été équilibré	Il/elle a fait plus que moi	Il/elle a tout fait

2. Est-ce que vous deviniez ce que votre partenaire allait faire ?

Pas du tout	Faiblement	Assez bien	Très bien

Donnez un exemple qui illustre votre réponse :

3. Est-ce que vous pensez que votre partenaire devinait vos intentions ?

Pas du tout	Faiblement	Assez bien	Très bien

Donnez un exemple qui illustre votre réponse :

4. Est-ce que vous avez adopté des rôles différents, avez pris chacun des aspects différents en charge ? ❑ oui ❑ non

Si oui, décrivez les différences et donner des exemples

5. Pour vous ce jeu était ?

Très pénible	Ennuyeux	Ok	Amusant	Passionnant

6. Pour votre partenaire, croyez-vous que cette jeu était ?

Très pénible	Ennuyeux	Ok	Amusant	Passionnant

Donnez un exemple qui vous inspire cette réponse :

Appendix 5 : results (1) : score and mutual modelling

Each line of this table presents the results of a pair. Pairs 1 to 9 were provided with the awareness tool unlike pairs 10 to 18. The variables are :

- the score obtained by the pair.
- MMoa→b : objective evaluation of how A estimates B's intentions during the 3 levels.
- MMob→a : objective evaluation of how B estimates A's intentions during the 3 levels.
- MMo1 : accuracy of the mutual modellign of a pair in level 1.
- MMo2 : accuracy of the mutual modellign of a pair in level 2.
- MMo3 : accuracy of the mutual modellign of a pair in level 3.
- MMog : global objective MM evaluation for a pair.
- MMsg : global subjective MM evaluation for a pair.
- MMsa→b : subjective evaluation of how A estimates B's intentions during the whole game.
- MMsb→a : Subjective evaluation of how B estimates A's intentions during the whole game.

Pair ID	AT	Score	MMoa→b	MMob→a	MMo1	MMo2	MMo3	MMog	MMsg	MMsa→b	MMsb→a
1	AT	127	1.67	1.33	2.50	1	1	1.50	3.50	3	4
2	AT	130	1	1	1	1	1	1	2	3	1
3	AT	169	2	1.67	2	1.50	2	1.83	3	4	2
4	AT	290	1	1.33	2	1	0.50	1.17	3	3	3
5	AT	293	2.33	1	0	2	3	1.67	3.50	4	3
6	AT	304	1.33	1.33	1	1.50	1.50	1.33	3	3	3
7	AT	322	2.33	1.33	2	0.50	3	1.83	3.50	4	3
8	AT	333	2	3.33	1.50	3.50	3	2.67	3.50	3	4
9	AT	360	1.67	1.67	0	1.50	3.50	1.67	3	3	3
10	No AT	51	1	0.67	1	0	1.50	0.83	2.50	3	2
11	No AT	84	1	0.67	1.50	0	1	0.83	3.50	4	3
12	No AT	152	2	0.33	1	1	1.50	1.17	2.50	2	3
13	No AT	183	2.33	2	0	2.50	4	2.17	3.50	4	3
14	No AT	198	1.33	1.33	1	2	1.00	1.33	3.00	3	3
15	No AT	213	0	2.50	1.50	0.50	0.50	1.25	3.50	4	3
16	No AT	232	3	3.33	3		3.50	3.17	3.50	4	3
17	No AT	233	2.67	2.67	2	3.50	2.50	2.67	3.50	3	4
18	No AT	235	1	0.67	1	0.50	1	0.83	3.50	4	3

Appendix 6 : results (2) : pairs action

Each line presents the sum of the actions performed by the two players within a pair. The actions are : the number of drone launched, the number of drone docked to the spacestation, the number of tools dropped in the environment, the number of tools dragged in space, the number of times the players changed their view and finally the time spent in camera/spaceship view (in milliseconds).

Pair ID	Drones launched	Drone docked	Tool dropped	Tool dragged	View changed	Camera view	Ship view
1	157	24	17	24	334	11063.59	3645.68
2	189	29	13	3	382	8759.52	2923.76
3	1064	201	8	7	512	10152.3	4199.76
4	419	62	23	23	278	9981.17	1705.08
5	132	26	10	12	164	9987.83	2902.65
6	710	27	18	18	619	9747.8	4338.85
7	265	43	22	20	265	10452.48	3286.92
8	396	124	13	13	480	9877.23	2885.37
9	412	95	6	12	428	10742.42	4130.04
10	571	40	19	19	195	8436.69	6342.43
11	232	36	7	7	325	12130.8	3152.02
12	1056	90	16	21	656	9146.26	6550.88
13	739	43	16	17	98	5276.78	2334.79
14	381	55	14	13	236	6786.28	1987.08
15	191	29	13	16	266	3529.38	10796.16
16	612	214	15	18	456	11687.66	3066.09
17	589	95	10	11	458	7602.79	3526.86
18	256	79	22	20	170	9645.86	3861.85