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Communication system and team situation awareness in a multiplayer real-time learning environment: application to a virtual operating room

Catherine Pons Lelardeux · David Panzoli · Vincent Lubrano · Vincent Minville · Pierre Lagarrigue · Jean-Pierre Jessel

Abstract Digital multi-player learning games are believed to represent an important step forward in risk management training, especially related to human factors, where they are trusted to improve the performance of a team of learners in reducing serious adverse events, near-misses and crashes in complex socio-technical systems. Team situation awareness is one of the critical factors that can lead the team to consider the situation with an erroneous mental representation. Then, inadequate decisions are likely to be made regarding the actual situation.

This paper describes an innovative communication system designed to be used in digital learning games. The system aims at enabling the learners to share information and build a common representation of the situation in order to help them take appropriate actions, anticipate failures, identify, reduce or correct errors. This innovative system is neither based on voice-chat nor branching dialogues, but on the idea that pieces of information can be manipulated as tangible objects in a virtual environment. To that end, it provides a handful of graphic interactions allowing users to collect, memorize, exchange, listen and broadcast information, ask and answer questions, debate and vote.

The communication system was experimented on a healthcare training context with students and their teacher. The training scenario is set in a virtual operating room and features latent critical events (wrong-patient or wrong-side surgery). Teams have to manage such a critical situation, detect anomalies hidden in the environment and share them to make the most suitable decision.

Analyzing the results demonstrated the efficacy of the communication system as per the ability for the players to actually exchange information, build a common representation of the situation and make collaborative decisions accordingly. The communication system was considered user-friendly by the users and successfully exposed lifelike behaviors such as debate, conflict or irritation. More importantly, every matter or implicit disagreement was raised while playing the game and led to an argued discussion, although eventually the right decision was not always taken by the team. So, improving the gameplay should help theplayers to manage a conflict and to make them agree on the most suitable decision.

Keywords digital collaborative environment · team situation awareness · communication · information ·

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decision making, · learning game · virtual environment · socio-technical system · non technical skills

1 Introduction

Everyone would like to live in a safer and more secure world. So, many risk management and disaster reduction programs were developed to prevent and avoid some serious events or accidents in aerospace, healthcare and nuclear fields. Many risk management and disaster reduction programs were developed to prevent and avoid some serious events or accidents.

Professionals investigate the near-misses, serious events and accidents aiming to seek out the failures, technical or human errors on the events which have led to the crash. The proceeding for identifying the errors or evaluating their causes aims to highlight the main contributing factors, particularly human factors such as a communication default or bad situation awareness.

Training for the management and prevention of risks in the area of aeronautics, nuclear, health or transport takes a great importance in a world that aspires to be safer. In these areas, many studies show that human factors are most often listed among the multiple causes of accident or near-misses. They are generally not caused by a single failure and they happen despite safety barriers. Studying complex systems, Reason [63] shows that most of the time, accidents result from multiple successive failures which could not have been corrected or stopped in time. Reasons model[62] proposes that within any complex system, multiple barriers or layers exist to prevent accidents or errors. Mostly they do this very effectively, but there are always weaknesses. Among them, a poor communication between team members is often identified as an underlying factor.

In complex systems, committing zero error is most of the time nearly impossible. The pursuit of greater safety is hindered by an approach that does not seek to remove the error provoking properties within the system at large. Advancing mistakes or identifying likely errors and then removing or correcting them before the accident would be a better way to improve safety.

Aviation security and safety and quality of patient care are some examples of contexts in which many near-misses, serious events or accidents are connected to a communication default.

In Aerospace, since 1988, different studies [18,71, 19] have shown the role of human factors and especially the role of the situation awareness in aerospace complex environment. Hartel et al [26] explained that a lack of communication was the lead causal factor in a review of 200 aviation mishaps. In aerospace schools, a wide variety of simulators are used to train professional pilots in different aircraft cockpits. The aim is to improve both technical and non-technical skills.

In the healthcare context, a lot of studies have shown that the most current origin of adverse events in the operating room is related to human factors and especially to communication defaults [42,25,34]. The Pennsylvania Patient Safety Reporting System is a secure, web-based system that permits Pennsylvania hospitals to submit reports of ”‘Serious Events’”, ”‘Incidents’” and ”‘Infrastructure Failures’”. In its annual report in 2007, the Pennsylvania Patient Safety Authority notes that communication problem was most often linked with reports of medication errors and errors in procedures, treatments or tests [56]. These events accounted for about 63 percent of all events reported mentioning communication as a contributing factor. The Joint Commission for Hospital Accreditation in USA reports [30] that 64 percent of root causes of sentinel events (3548 adverse events reported between 1995 and 2005) involved a communication default.

1.1 Socio-technical system

A social system is composed of people who must work together in a limited space and time. In such a system, individuals share a common goal and manipulate a set of technical objects, specific equipment and documentation which help them to fulfill their professional requirements. Technical objects and specific equipment embed software that gives dynamic pieces of information to inform the professionals on the situation as a monitoring system. Most of the time, a socio-technical system is composed of a combination of human-human and human-computer interactions.

A socio-technical system is more or less complex and this complexity can come from different sources: (1) different disciplines, expertise and cultures coexist within the team, (2) the operators deal with unanticipated events, (3) the operator's interactions are non linear and often unpredictable, (4) humans interact with each others and with technical objects or computer systems which deliver technical information, (5) the state of the system changes and evolves over the time.

In the healthcare context, Vicente [76] lists several contributing factors to teamwork system complexity. Effken [15] describes health care as a complex dynamic socio-technical system in which groups of people cooperate for patient care and are faced with numerous contingencies that cannot be fully anticipated. The operating room is so a complex and dynamic socio-technical system. It gathers different people as the surgeon, the anesthetist, the operating nurse, the anesthetist nurse, the patient and technical or monitoring equipment: anesthesia machine, electric generator for the scalpel, surgical aspiration system. . . The complexity of this dynamic system comes from multiple elements; the composition of the team is heterogeneous. Each one has their own technical skills and responsibilities. There are multiple interactions that influence the evolution of the system. But, a successful operation depends on what information is dynamically exchanged [57].

Often participants in healthcare delivery conflict with each other because individuals follow different sub-objectives; this misalignment can produce inefficiencies, unexpected situations and different care problems. A dozen of dimensions of complexity in health care are described by Carayon [6], Plesk and Greenhald [58] and Effken [15].

As human interactions or human-computer interactions can produce hazards, paradoxes can appear and accidents or adverse events are hardly predictable. In the operating room, different disciplines are represented as surgery, anesthesia, and nursing. Each professional deals with a large variety of pathology. They are free to act and communicate. Their actions and purposes are interconnected and aim for the same main global goal. Any action and communication have an impact on the state of the system. Sometimes, the team can visualize dynamic information: for example on monitoring equipment, the patient's clinical data change in real-time and are represented on graphics. During the operating time and depending on the period, the surgeon can join the anesthetist on a specific task and then join the operating nurse to accomplish another task... Different groups inside the team are composed for an objective and each one exists for a very short time, namely until the goal is achieved.

Before training on non-technical skills and risk management, the individual technical tasks have already been studied. Every one knows their job and tasks to accomplish to fulfill their role and helps the team reach an identified common goal.

Each operator tries to build the most probable representation of the world, working out the information collected on the changing environment. For example, while the anesthetist nurse prepares the material for the anesthesia, the operating nurse prepares the patient's operating instrumentation on a table, the surgeon and the anesthetist check together the position of the patient on the operating table.

1.2 Communication

Human interactions are based on communication. Keyton et al. [33] note that communication is often represented as a simple process between a sender and a receiver or within an information sharing model, yet sending and receiving messages use symbols as the meaning given to a message. Shared meaning is complicated because during communication, interaction operates in both directions between the sender and the receiver: each one is both sender and receiver simultaneously and the meaning is co-developed within the interaction. Keyton [32] stresses the difference between the macrocognitive framework and the communication framework: "The macrocognitive framework emphasizes a team's shared mental models whereas a communication frame emphasizes that shared meaning among team members is more frequently implicitly than explicitly recorded in their messages. Both acknowledge that communication (in macro-cognition) or messages (in communication) serve as an index of team members' goal-directed behavior. The two approaches differ in the role of communication: as information exchange in macro-cognition as compared with verbal and nonverbal symbols composing messages for which senders and receivers coconstruct meaning". Here, the word communication refers to macro-cognition.

1.3 Team situation awareness

Communication helps individuals to build their own representation of the professional case they have to manage. As each team member has their own knowledge and outcomes, different individual representations are built if there is not enough communication between teammates. Each one bases their representation on their own perception, on their own comprehension of the current situation according to their level of attention and experience. But, all team members need to know certain pieces of information to build their own representation of the situation from their own perspective. And, then, they try to exchange their vision with the other team members to be ready to anticipate predictable difficulties and make safer decision.

The lack of communication results in a limited and erroneous representation of the global situation by the team. Therefore the team makes their decisions based on their restricted mental representation, which could breed inadequate decision-making regarding the real living situation. Endsley [17] defines the situation awareness as "a perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Kaber and Endsley [31] consider the situation awareness (SA) as "the sum of operator perception and comprehension of process information and the ability to make projections of system states on this basis". Team Situation Awareness (TSA) is one of the critical factors in effective teamwork that can impact the success of the final achievement. Mathieu [48] showed the influence of shared mental models on team process and performance by testing 56 undergraduate couples who train on flight simulator. Another important factor is the role of expertise in a dynamic system [12]. Sharing information between the members of the team should allow the team to build a common and more realistic representation of the situation. Therefore, they should be able to make more appropriate decisions because they should be able to evaluate the situation in a better way.

2 Goals and challenge

2.1 Challenge

One of the critical components of a comprehensive strategy to improve the safety of a patient as well as an aircraft flight is to create education and training environments that support healthcare providers to train people to identify errors, evaluate causes and take appropriate actions to improve their performance in the future. Whether in aerospace, healthcare or nuclear safety, professionals carry out inspections to investigate serious complaints, serious accidents and near-misses, incidents and occurrences of non-compliance. Most often, among the origins of accidents or near-misses, a communication default is involved.

In risk management and disaster reduction programs, innovatory programs have been launched to train and educate students and experts on risks resulting from human factors. These programs aspire to make people understand that zero human error is an uncertain goal to reach. But, the most important objective is to train people end especially teams to anticipate difficulties/risks, to identify a near-miss or an error and then correct or reduce it by sharing information and making the best decision possible. One difficulty is to demonstrate the importance to train every team member on risk management because each one is self-satisfied and persuaded to be good enough to manage risks thanks to his experience and good technical skills. It is difficult to explain without teamwork simulation that sometimes the least graduated team member is the one who has the most relevant information that must be trusted for a specific critical moment. Another difficulty is to highlight the importance to apply security procedures and to adapt them according to the ongoing critical situation. All too often, a security procedure is seen as a new administrative procedure pushed by the company. On the other hand, learning is a process which is constantly modified by experience [35]. To train people on near-misses or critical situations, the digital environment should present teamwork situations where operators can both act and communicate as in a real professional context. To teach them non technical skills as leadership, decision making and situation awareness the digital environment should present standardized situations as well as critical situations in which anomalies are hidden into the socio-technical environment. Such a learning environment may make team improvement possible by experiential learning. Designing an environment with a large library of known critical situations or near-misses could support providers to train and educate professional teams on risks management. The main goal is to design a virtual and real-time collaborative universe which represents with great fidelity the structure and complexity of a virtual socio- technical system where teams could experiment training situations involving critical risks or near-misses linked to communication default. The second goal is to evaluate the communication system and its usability. The third one is to check the ability of the team to share a common representation of the situation, and make the most suitable decision. But it is not possible to evaluate its performance against a clear specification of what the system should reveal, because this is unknown. This environment must feature both a contextual action system and a communication system. It must allow controlled manipulations of the decision context and controlled information available to the operators involved. It must provide features to make contextual actions on technical monitoring equipments, to speak to each other, to give an opinion and to argue on different topics. The virtual environment which represents a socio-technical system provides different sources of information for humans: technical documentation, monitoring equipment and virtual characters which are not controlled by a human player. This innovative environment is designed to be used in a learning context. Therefore, this training context requires to record learner activity to show a dynamic, automated and personalized debriefing at the end of the training session.

In such an environment, the team needs to be able to check if the situation is correct or not. If it is not, the operators must be able by using available interactions and features to identify the problems, to communicate and make decision. Using a multi-player and real-time game environment as a learning game is one direction to explore.

In this article, the focus is placed on fully digital training environments and in particular on the digital learning games which could provide a virtual socio-technical training environment to learn and improve communication in order to make more suitable decisions. The main constraint is the real-time constraint and the main difficulty is to propose interactions that can allow humans to naturally interact and communicate with virtual humans as in a real-life professional case. The sections below describe the data models and GUI interactions underlying communication: perception, attention, information research, memorization and decision making.

2.2 Requirements and limits

The main features of the environment are expected to reduce risks generated by a communication default providing virtual situations identified by experts. In this virtual socio-technical universe, professionals do not train on technical positions and moves.

In this virtual world focused on collaborative and team-working, communication system takes a fundamental place. The requirements of such a communication system are defined as follows:
Firstly, the ways of communication must be intuitive enough for the learners to share information naturally;
Secondly, every information shared must also be easily captured and understood by the game so as to deliver the most relevant feedback to the learners individually or to the team as a whole;
Thirdly, the collaborative decision-making must be as intuitive as possible. Different points of view must be able to be presented. Everyone must be able to argue his opinion/vote.
Fourthly, the game engine must be able to consider the issue of a vote. On the basis of the collaborative decision, the game engine must direct the team either to another stage or to a game over.

In this paper, we describe a communication system which attempts to mimic a human-like spoken dialogue based on information sharing and spreading in a group, although restricted to a very specific context. We don't focused on environment action model even though this one is the basis of manipulation of information. The system has been designed with the goal of being the simplest and the most usable model to comply with the above-mentioned requirements.

As a consequence, the reader must keep in mind that the system has been deliberately designed to present some limitations with respect to how communication is usually understood in a general context.

Particularly, the communication system presented in this paper does not intend to simulate natural dialogue, either verbal communication nor non-verbal communication. In concrete terms, the communication is defined according to the macro-cognition framework : ie : build mental model of the situation by collecting and sharing information between team members in order to build a common vision of the situation which should be the closest to the true one. So, as the team situation awareness is based on perception, attention, information research, decision making, this paper propose models and interactions to implement these features in a virtual learning environment.

The unquestionable fact is that to lead a coherent communication, each participant should uses his memory and exchanges known information. So, to combine communication system to contextual action system, the virtual environment must embedded a memory system which should store collected information before the user can use it. So, the paper presents a communication system based on a virtual memory system which manage virtual memory of each operator.

3 State of the art

The question of the communication inside a virtual environment can be approached from different points of view: verbal communication such as speech with semantic syntax, written utterance, spoken dialogue, chat conversation . . . or non-verbal communication such as presence, gestures, facial animation, real-time face and body animation, emotion modelling . . . . The avatar's representation in a virtual world is even more important in a real-time collaborative virtual world. Capin et al [5] list crucial functions in addition to those of single-user virtual environments:

- perception (to see if anyone is around)
- localization (to see where the other person is)
- identification (to recognize the person)
- visualization of others' interest focus (to see where the person's attention is directed)
- visualization of others' actions (to see what the other person is doing and what she means through gestures)
- social representation of self through decoration of the avatar (to know what the other participants task or status is).

Many researches have been done to develop chatbots, to synchronize virtual character's faces or body motion with their speech and combine interaction with specific animations and rendering[44, 36, 16].

All these components contribute to a better understanding on what is going on in the collaborative virtual scene, but this article focuses on how to represent verbal communication in a multiuser environment.

First of all, representing verbal communication imposes to respect some implicit rules of real conversation.

3.1 Implicit rules of a natural professional communication

In face-to-face dialogue, conversations generally follow implicit rules as choice of a common conversation topic, choice of the listeners, turn-talking rule ... In 1970's, Grice [24] argued that people in conversation must be cooperative. Speakers must try to "'make their contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which they are engaged"'. In a face-to-face group conversation, the listeners need to know if the speaker talks to the whole group or if the speaker contacts a particular group member. Somes cues such as eye contact, gaze, body orientation, and gesture enable speakers to know to whom listeners pay attention or whom the speaker is talking about [14].

Either in a face to face conversation or in a phone conversation, talking about something needs to identify a common topic to maintain the coherence of discourse. Topics in a professional conversation are generally well identified and conversation follows generally a purpose. And, successive speakers in a conversation are participating in a single conversational thread.

The notion of sequential relevance or adjacent turns in a conversation should relate in some way to what has gone before. Therefore, the memory underlies the dialogue. So, the communication system presented in this paper is based on a virtual memory system: each character has a virtual memory that stores any piece of information collected in the universe.

Another implicit rule relates to what conversational analysts call the turn-taking system. It ensures that the one who speaks is listened by the others or that the participant who speaks should not get cut off [68]. Therefore, reproducing a professional conversation in a virtual world requires to consider the technical context and the communication as a coherent whole. Moreover, exchanging information and determining relevant information participates to maintaining coherent conversation.

Further, in real life, when one person speaks, the hearer not only listens but lets the speaker know he is understanding with head moves, yes's, "'hum'", and other so-called back channel responses [13][23].

The communication system described in this paper proposes features to allow avatar's conversation and decision process. It is be based on the implicit rules of real conversation :

- perception (to memorize the current contextual information : pieces of information sent by someone else or collected by itself in the environment)
- identification of the speaker (to recognize who is speaking)
- topic (to see what is the topic of the conversation)
- value (to see what is the current value of the information at the moment)
- visualization of turn-talking rules (to see when a person is speaking and if the other is listening : visualization of a question and the answer sent or a new piece of information received)
- visualization of others' conversation focus (to see what is the topic of the others teammates' conversation)
- visualization of everyone's point of view (to see what is the opinion of each one on a specific topic)
- identification of the leader (to know who is responsible of the final decision)

The model of dialogue and metaphors to speak, ask something, answer to someone, take a view on a topic, debate with the team have to be effective. And there are different possibilities to simulate a verbal conversation between two humans: (1) a human participant talks to another human participant by text chat or by voice chat (2) a human participant talks to a computer and the computer transmits to another human participant (3) a human participant sends predefined information to another human

The next section describes the advantages and inconvenient to adopt these possibilities in a learning context. The first possibility could use chat room or internet relay chat. In the second one, the computer needs to recognize human speech of the sender or the human participant needs to learn a specific vocabulary to communicate with the computer; on the other hand, a voice dictation system is needed to transmit the message to the human-receiver.

3.2 Text-chat systems

Among the large variety of verbal or textual communication system available on the Internet, the chat room or the Internet relay chat can be mentioned as synchronous systems.

Internet relay chat, or chat rooms are available virtual online environment where people congregate for conversations. In these virtual places, participants conversations have several topics being discussed simultaneously and most chat rooms require participants registration. To register, participants have to create an account with a nickname or a pseudo; this pseudo is visible to others participants. A presence system informs the group if someone is connected or not. In 1990's, conversations and interactions in chat rooms took place via text that was visible to all participants [28]. People could write and read text in real-time. As people add text, it continually scrolls up yielding an digital log of the conversation.

Herring [28] who analyzed text-only computer-mediated communication showed that online conversations violate traditional conversation rules. Most of the time, messaging systems on turn-taking and reference impose limitation and are interactively incoherent. Yet, despite its relative incoherence, users enjoy using it.

In web 2.0 chat rooms, feed backs help users to improve coherence. Notification system informs the sender when the participant is connected and if the message sent was sent by the system and if the message was received and read. A main characteristic of online chat rooms is that they are inherently visual contrary to traditional phone system. Participants use visual strategies to communicate both writing and using graphical icons like emoticons. These strategies facilitate coherent online conversations.

The Software "'Snapchat'" is an example of social chat systems available on mobile phone or tablets. It allows users to communicate by sending short videos, pictures, emoticons, writing texts. The feed backs help people to communicate either in a synchronous way or in an asynchronous way and the messages disappear by itself after few hours.

Both notification system and presence system should be interesting to implement into a collaborative virtual environment to train on risks linked to communication defaults.

But chat room conversation cannot be controlled easily to automate a debriefing on what was wrong or right during the training session. In chat room, the conversation topic is free and no one controlled if someone is right or wrong contrary to what is expected at the end of a learning session. In consequences, chat room system is not easily scalable to automate a debriefing session both based on actions done in the virtual universe and information shared in a virtual chat room. For the same reasons, using the voice-chat limits automatic debriefing feature that is a very important educational part of the training.

The communication system described here doesn't use neither text-chat system nor voice-chat system to converse but it uses a presence system and a notification system.

3.3 Spoken dialogue interface

Spoken dialogue systems have been defined as computer systems with which humans interact on a turn-by-turn basis and in which spoken natural language plays an important part in the communication [20].

Sometimes, the Wizard and Oz technique is used to specify the future system behavior and the interaction between the computer and humans. Wizard and Oz simulation is quite simple : a human plays the role of a computer and simulates a human-computer conversation[74]. Fraser et al [21] define a taxonomy of Wizard and Oz to simulate human-human interactions.

Spoken dialogue systems are classified into three main types. These domains correspond to the different methods used to control the dialogue with the user: (1) finite state- (or graph-) based systems; (2) frame-based systems; and (3) agent-based systems [74].

In a socio-technical system which involved more than 4 participants, more than hundreds specific actions by participant could be available. So, the scope of possibilities is very wide. The system that could be based on natural spoken language input, single words input, sentence spoken input, or on unrestricted natural spoken dialogue should be powerful enough to assure a real time recognition and voice dictation.

Understanding natural language is far from trivial for a computer, let alone understanding the context and the meaning of each utterance. Natural language understanding (NLU) is still considered as a source of recurring failures, and therefore traceability is compromised.

These last years, advances technology regarding computing power facilitated many commercial and industrial applications based on spoken dialogue research results.

As the Audio Speech Recognition (ASR) technology provides poor results[52], Audio-Visual Speech Recognition (AVSR) is one of the advances in Automatic Speech Recognition technology[50][43]. It combine audio, video, facial recognition to capture the user's voice.

Despite all technological advances, models and technology involved in spoken dialogue system, speech and recognition technology and artificial intelligence field would not be sufficient to make possible real-time analyze of the speech between many people or/and emotional faces synchronization with verbal speech.

Moreover, most of the time, the spoken dialogue interface is used to communicate because the user can't execute order using his hands. For example, the 'Command and control' applications allow the users to execute orders with the vocal input which would be otherwise executed using the keyboard or the mouse. An example of application is the communication between the driver and the dashboard of the car. In the virtual digital environment, the users already use a keyboard and a mouse to execute actions which are also easier to record.

The communication system described in the next sections is not based on spoken dialogue but the environment is defined by a graph of finite states based on different systems as communication system, character's virtual memory system and contextual actions system.

3.4 Learning games

Among serious games [49,39], digital learning games use features of video game play and game technologies, present good look-and-feel interactive interfaces, interactive digital storytelling (metaphoric or realistic) [39] to involve players and present feedback to allow users to improve their performances in the next game sessions. As entertainment and education are mixed, they present an hybrid model in order to motivate, train and evaluate people in a different and innovative way. The students, the teachers and all educational and training providers are the aimed public.

Digital learning games could be defined in the following equation:
features of video game play and game technology
+ learning scenario embedded
+ feedback and reporting system
= digital learning game [60]

On the teacher side, the learning game is a software which proposes training situation on educational or professional subjects embedded rules and models based on scientific results. It can be used in the classroom or in Open and Distance Learning (ODL) to introduce a concept to students, to make students continue to build on their achievements, to improve student's performance or to evaluate students' skills and knowledge. Gamification [77] seems to help students to increase both their involvement in carrying out an activity, and their ability to problematize and resolve the problems based on technical know-how and expertise. Teachers can use the learning game to put students in context and the virtual interactive experience impacts student's learning. Learning game do not replace object's manipulation in technical training neither training exercise in the real professional environment.

The learning game is shown as a gamified exercise or educational activity in an artificial environment which is more or less faithful to the reality context. Sometimes, learning games represent a complex technical situation as manufacturing procedure with numerical command machine tool [61], sometimes they present human-like conversation situation as business talk between customer and seller [2,11].

On the student side, the learning game uses various features of the video game play. Using storytelling, the game proposes a mission which fixes a main goal.The storytelling invites students to play a characters role and involve students in a virtual world where they can use features to act, exchange, challenge themselves to get the victory, compare themselves with the others... The storytelling gives the primary objective underlying an educational path. It hides identified educational objectives in order to train, evaluate or introduce an educational concept by doing. Teachers know the prerequisite knowledge, the skills and outcomes to mobilized to achieve the mission or to successfully perform the gamified exercise. Learning games use video game levers to activate motivation as monetary systems, score systems, experience level, inventory, collect of items, talent tree, reward system, system for building objects from items collected...

Rilling et Wechselberger[66] propose a framework to support both game play rules, game mechanics and educational concept.

Inside the learning game, students use interactions that are available on software application. At the end of the gamified activity, the student was shown what kind of error he made and how he can correct it in a future. The tracking system displays to the teacher indicators on students' activity as "success" or "failure", play time... Feedback informs the students how well they are progressing in the gamified activity and indicates whether it is necessary to adjust or it is possible to maintain the current strategy on progress. Feedback guides the students but leave little doubt about what is the next action to do. This "flow" [10] represents an import aspect to motivate learners. To display feedback to players, the game engine includes internal reporting system which represents one mechanism to enhance students and teacher understanding of errors and the underlying factors that contribute to the game over. This reporting system makes possible a personalized debriefing to identify student's personal mistakes, to analyze them with a systemic approach, to evaluate root-causes and shows the appropriate actions to improve performance in the future. The tracking tool system may present an overview of the classroom results to check the learning dynamics of students.
In a collaborative learning game, non-playing characters (NPCs) are likely to be resorted to to replace missing players or to play uninteresting roles, educationally-wise [70]. Those NPCs must be considered as fully equal partners [75]. Therefore, they must not only be in capa-

bility to understand the communications of the learners as much as their actions, but they must as well be able to participate in those communications.
The question of the level of realism to represent the virtual universe is not a second zone question. Malone and Lepper[46,40,45], concerning the world of digital games for learning, define a fantasy universe as “one that evokes mental images of physical or social situations not actually present”’.

But, the way to represent the real context can have an undesirable effect on education goal in a learning context. Actually, Gooden et Baddeley [22] showed the impact of the learning environment on the recall when subjects must learn something. ”‘Recall is better if the environment of original learning is reinstated”’. So, the virtual environment described here reproduce the reality of the professional context with technical equipment, materials, characters... but the level of realism displayed on the graphical screen try to support the professional context and the educational content as a coherent whole. On the other hand, sound design can have an impact on task performance using digital training [9].

Multiplayer games with communication features: Many video games for entertainment invite team to reach a common goal and provide tools for player’s communication in game. Starcraft 2 [59], Jedi Knight II : Jedi Outcast are some examples which provide voice-chat or text-chat to communicate but “3D Virtual Operating room” [37] is probably one of the firsts digital learning games trying to improve teamwork providing tools to simulate virtual information exchange and show feedback based on the players digital conversation during game session.

Digital learning games are one kind of training environments in which environment and scenario are both artificial. They are becoming serious competitors to real-life simulators for the professional training, in particular in the highly technical business where their cost-effectiveness is a considerable asset. But, the more expertise level learners have, the more fidelity level they expect. Therefore, to give to the player a feeling of high fidelity related to the professional context, the game play would be really very restricted. It is difficult to strike a balance between game play and fidelity to real professional world thus, using different training contexts is probably an issue. In any particular training situation, environment and scenario are interspersed. But sometimes, there is a mixture of reality and virtuality as illustrated in figure 1. The concept of a ”training continuum” relates to the mixture of classes of objects presented in any particular training situation. Real professional environments, are shown at one end of the continuum, and virtual environments, at the opposite extremum. On the far right, the case defines environments consisting only of real objects in a real professional environment; baseline situation includes authentic and real cases. Learning session includes for example what is observed via a conventional video display of a real-world scene. An additional example includes direct viewing of the same real scene, but not via any particular graphic and electronic display system.

The following case, at the right, defines environments consisting only of real objects in a real professional environment; baseline situation includes an authentic case which has been redrafted and designed for training. An example of learning session would be a session during which actors play character’s role like in a theater and students try to manage the situation by using real objects and human-like objects as virtual patient even if the situation presents a virtual case. Therefore, as indicated in the figure, the most straightforward way to view a Mixed Reality Learning Environment is one in which real and virtual world objects and virtual training case are together within a single learning session [41,8].

The latter case, at the left, defines environments consisting solely of virtual objects in a virtual environment and presents only training virtual situation. An example is a learning session based on a digital learning game which proposes a virtual professional situation designed for training. An other example would be done with a conventional computer graphic simulation.

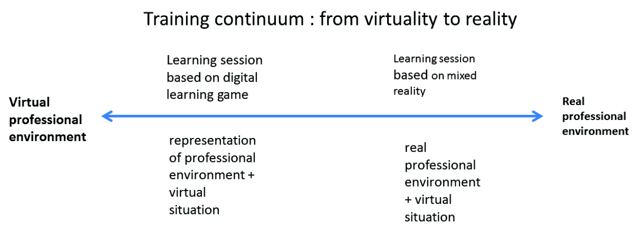

Fig. 1 Simplified representation of training continuum : from virtual to real professional environment

3.5 Human-like communication in virtual world

Virtual digital worlds use generally limited metaphors and interaction to represent human-like communication either between a non-player character(NPC) and a player or between two player’s character. Some games combine discourse with facial animation to help users to understanding spoken text in noisy conditions. Thus, the users can detect non-verbal conversation and emotional signals. But most of the time, designing character's facial animation with avatar's authoring tools remain cumbersome [53]. In the case of a conversation between NPC and player's character, most conversation are restricted to one way. Only, the NPC talks to the player's character. The GUI displays only text with timed-scrolling system to get a character to talk to a player. In the case of a conversation between 2 characters, most games focusing on communication skills and team-working knowledgeably use a voice-chat system and give up on the possibility to automate – even partially – the debriefing. This is the case for Clinispace [55] (Innovation in Learning Inc.) and 3DiTeams [73] (Duke Medical Center and Virtual Heroes), two learning games for healthcare training inside which the human supervisor must be part of the game in order to listen to the conversation and use them for debriefing the players once the session is over. In spite of the difficulty, one successful usage of NLU in a game must be noted. In the game Façade [47], the player can talk naturally to the non-playing characters (NPCs) and get an appropriate response most of the time.

This suggests that such a system could as well be used for debriefing a game session, however unreliably. Besides, related domains of application like embodied conversational agents, which are virtual agents able to demonstrate verbal and non-verbal communication [7], and conversational intelligent tutoring systems [67] have reported significant advances in natural language processing techniques, and the benefits of using them are increasingly advocated [27].

Chat systems are easier to manage since the voice recognition stage is unnecessary. They are very common in games. Historically, Lucas film's Habitat [51] was the first game to allow multiple human players to communicate in a shared virtual environment via text- chatting. In second life, a chat console is at hand for the players to communicate with each other or with chat- bots. Chat-bots are virtual characters controlled by a script and whose answers are based on the syntactic analysis (i.e. parsing keywords) of the learner's utterances. For instance, in the Indiana University Medical School Virtual Clinic [29], one can converse with a virtual patient in order to investigate their condition and formulate a diagnosis. However, understanding the content still remains a problem. Moreover, chat is less natural, less efficient, since at least voice- chat keeps the hand of the player free for actually playing the game.

The pinnacle of traceability in games consists in using dialogue trees. In a dialogue tree, every utterance, question or answer is scripted in a tree-like structure. The system is very common in single-player adventure games to design the dialogues between the player and a non-playing character. Each line of dialogue from the NPC calls for several responses from the player, each of which continues the dialogue the same way a tree is being explored by an algorithm. Obviously, the drawback of this technique is the work required to think ahead and write every line of dialogue. This is even more complex when both the interlocutors must be proposed several choices. Therefore, in a multiplayer context, not only Herculean is the task but it seems nearly impossible to provide choices for every discussion that the players are likely to engage in, even in a controlled context where the topics of discussion are controlled. Despite the limitations of this technique, traceability is optimal since the manipulated objects have been designed in advance and are therefore known and easily recorded.

Predefined dialogues are therefore frequently in use in learning games; adequate authoring tools are resorted to in order to ease the writing.

4 Virtual universe

The virtual collaborative environment that is described here features and combines different digital systems and graphical interactions: a communication system, a contextual action system, a virtual memory system and a voting system to reproduce the dynamics and the complexity of a multi-point inter-professional conversation. Then, it should offer features turn out that the team behavior which may conduct to critical errors or near-misses.

Users are presented with a first-person perspective of the environment. Their character is not allowed to move. They have a default view of the scene and can't move. They can use their specific equipment and materials. For example, the surgeon can use the laser surgical knife, the microscope whereas the anesthetist can manipulate drugs...

The scene is represented as 2D view and icons allow users to access to a specific documentation and some specific features as vote topics (see figure 2).

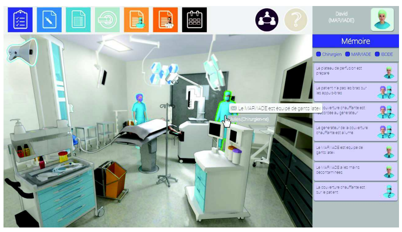

Fig. 2 The virtual 2D universe contains communication system and contextual action system that allow users to experiment a socio-technical situation.

The individuals, grouped in a virtual team, play the role of different professionals in this digital simulation representing the socio-technical system. For example, one individual plays the role of the surgeon, another one plays the role of the anesthetist, another one plays the operating nurse...

In such environment, individuals can exchange information, act and cooperate so as dynamic and interdependent way in a scalable environment[69]. To promote communication between team members, different levers are used:

- the virtual world reproduces faithful professional situations
- the team has a common mission to fulfill
- they should manage situation where near-misses and/or anomalies are hidden
- the players cannot succeed unless they reduce risks by being aware of the situation and making the best decision
- the pieces of information are dispatched inside the virtual environment
- each player has a different characters role
- each character can access to pieces of information unavailable by the teammates
- specific tasks and set of actions are available for each different character's role. They depend on the current status of the environment.
- each character can reproduce technical tasks and investigate on the current situation

The game environment should be faithful to the professional environment in such a way as to retain the cues of professional situations. The contextual action system described bellow allow users to accomplish individual tasks and to ask their teammates to coordinate themselves to accomplish collaborative tasks.

4.1 Registration system

As in a chat room, students need to connect to the environment with a password and a pseudo but they have to select a character's role among those required to run the learning session. Their pseudo and their character's role are visible to others participants. It is possible to run a learning session even if the team is not complete. Then, an artificial intelligence controls and simulates the character's behavior of NPC[70].

4.2 Contextual action system

The virtual universe is represented by a set of objects as technical equipments, documents and avatars. For example, the universe of the virtual operating room is composed of a surgeon, an anesthetist, an operating nurse, an anesthetist nurse, a patient and technical equipments: anesthesia machine, electric generator for the surgical knife, surgical aspiration system, table with basic anesthesia equipment... In this virtual world, player can freely interact with technical equipment and others characters using point and click on an object. Each object is represented by a set of status. The current state of the system depends on the status of each object. The user accesses to a set of actions by clicking on an object. Any action can change the status of the object and more widely it changes the current status of the whole environment.

Using point and click, the player displays a menu of actions and selects the action he wants to do on this specific object. Each action is associated with an object that is displayed into to universe. Thus, they investigate and reproduce real professional tasks. According on what players do, the current status of the environment is changing. The group of action available on an object depend on the current state of the system. More actions are unlocked as the player accomplishes certain tasks in the game. Sometimes, the current status allows the access to a limited group of actions if the team has to manage a climax stage or if they have to face a temporary critical challenge.

The members of the team can be involved in the mission at different time with different tasks to accomplish :

- individual
- collaborative task

4.3 Contextual sound system

The universe has a sound scape and some contextual action when selected make sounds. For example : the contextual action "'have a drink'" makes sounds and the users can hear people chatting. Another contextual action "'joke with the patient"' makes sounds and the users can hear people laughing.

But no sound signal from action are emitted to transmit a feed back on what is right or what is wrong at this step.

4.4 Automatic tutor system

Even if tasks and conversation topics are controlled by the designers, users are free to act and manage the situation as a professional team. Therefore, there are a large variety of paths that can lead to a success. Each virtual team could find different ways either to fail or to success to manage the risks arisen from the situation. The current situation status is composed of values of global variables, actions made or not, information known, information broadcast... The game engine uses this current status to inform the team on what objectives are achieved or not and what risks have been reduced or not.

5 Teamwork communication system

This section describes the communication system that make possible virtual dialogue between teammates. The system tries to respect implicit conversation rules to ensure a minimum of coherence in the conversation. The communication system allows the player neither to write nor to formulate information. This system is based neither on spoken dialogue nor voice-chat nor text-chat. The figure 3 illustrates the main features of the communication system.

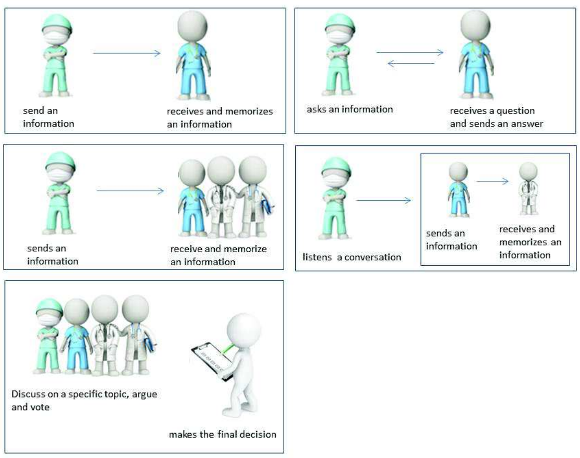

Fig. 3 An overview of the communication system.

5.1 Information

Information seeking and individual activity are bound intrinsically. Leckie et al[38] and Reddy et al[65] consider that information seeking can be conceptualized as an individual activity. "Information seeking is conceptualized by many of these models as an intrinsically individual activity for two major reasons: (1) a focus on the conventional pattern of interaction between a single user and technology and (2) the emphasis on individual, not on collaborative work."[64]

Inside the virtual environment, a hundreds of actions are available on objects as equipments, documents... By clicking on an interactive menu, player can realize a part of a global task and acknowledge a piece of information. The collected piece of information is represented with an information bubble associated to a context. For example : an object (as the patient which is a NPC in this example) contains associated information and action to reveal the hidden information (see table 1)

Table 1 Action, information according to a question. Information: "Patient.identity"

context	label
action or inspect	Ask to the patient their identity.
positive or standard answer	The patient identity is Pierre. Lemarin, born 30th march 1975.
negative or anomaly answer	The patient can't say its identity.
request	Do you know patient identity ?

Inside the virtual environment, every piece of information is represented as a floating bubble where the label is displayed (illustration in Fig.7) along with the source(s) or sender(s) of the information which are depicted by thumbnails representing the corresponding characters. The background colour of the bubble also gives a hint regarding what or who is concerned by the information. Table 2 lists the colours used in the game.

Table 2 Colours are associated to information bubbles in order to help the player during the retrieval process

blue	information concerns a NPC character X
green	information concerns a conversation involving X
purple	information is about an equipment
yellow	information refers to a collaborative decision
orange	information refers to a document or a field within a document

In the real professional context, each one follows their own purpose in an individual way even though they share the same common goal. All these individual tasks need to be well coordinated to reach the common goal. Everyone can generally see where the others teammates are located and what they are doing. The location, the gesture animations and motion of characters give general indications about the current activity and more generally about the current state of the environment. But as the environment is not dedicated to simulate with high fidelity technical and professional gestures, simple information linked to an action should be sufficient to inform the teammates on task that has been done 3. A task can be accomplished by a set of successive technical actions. At the end, the player collects an information resulting as “task X is done”, “Task X cannot been accomplished”...

Table 3 Actions are associated to information bubbles in order to help the player to inform the team about their work done

action	introduce yourself to the patient
information	introduce yourself to the patient is done

Pieces of information allowed in the game for learners to communicate are facts about the environment. Facts, straightforwardly issued from the objects, are pairs of attribute/value, meaning that every attribute from every object is likely to be used as information. For instance, `ECG.on=true` and `patient.asleep=false` both represent information (the ECG is powered on; the patient is awake). For the sake of intelligibility, a piece of information is associated to a label-action before being displayed to the player. Depending on the context, one piece information can be translated into four different labels. There are 4 contexts: when the value is true (positive/standard information) or false (opposite/anomaly information), when the value is unknown (must-be-inspected information), when the piece of information is meant as a question (request information) or when the label-action is unavailable to the current player. For instance, Table 4 lists the different meanings associated to the attribute `Patient.arterialpressure` depending on these contexts.

Table 4 A piece of information can be presented differently following the context. Information: “Patient.arterialpressure”

context	label
positive, standard	The patient arterial pressure is normal 12.7.
negative, anomaly	The patient arterial pressure is abnormally high.
inspect	Evaluate the arterial pressure of the patient.
request	Do you know patient arterial pressure?

5.2 Virtual memory of a character

A virtual memory is set to each character to store all information which will be collected during the game session. This concept of character’s virtual memory should allow to avoid the lack of expressiveness in the future virtual exchanges. The virtual memory (character’s memory) and the player’s memory are different. So, the game engine needs to synchronize character’s memory and player’s memory to allow players to exchange information between their characters. For that purpose, it is necessary to store information and build a kind of warehouse of character’s knowledge based on GUI’s events. Doing that, players should be able to select information into their virtual memory if they want to broadcast it to another character or to all the team members.

To build a character’s virtual memory and to synchronize it at a minimal level with the player’s memory, the game engine needs to listen to events to update information into the character’s memory. Events listened are contextual actions as ’do something’, ’listen information’, ’read information’, ’receive information’.

Indeed, when a task is accomplished, the associated information is stored and displayed on the virtual memory panel. On GUI, the virtual memory is represented by a panel filled with information bubbles (see figure 4). The virtual memory panel displays piece of information

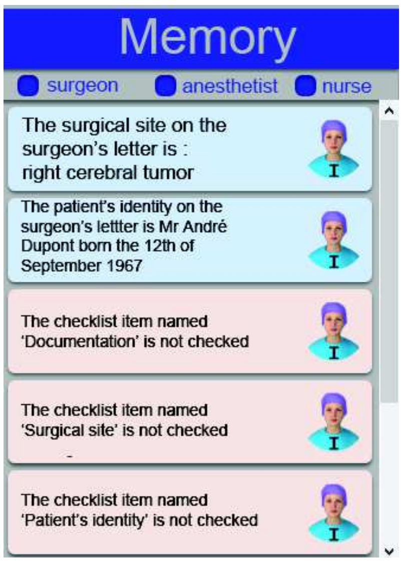

Fig. 4 The virtual memory of a character contains information acquired.

collected inside the environment and piece of information received from another avatar’s role.

While being received, an already existing information in memory is pulled to the top of the panel. The object/attribute couple is what makes two pieces of information come under scrutiny every time a new information is received. The value of the attribute and the source are two varying properties of a piece of information. Depending on them, various interpretations are likely to be made by the learner, as Table 5 shows. When the exact same piece of information is repeated, it is simply pulled up to the top without any other form of processing. When the entering piece of information updates the previous one, the bubble is updated, pulled to the top and flashes for a few seconds. When an existing piece of information is confirmed by a new one, the corresponding bubble inside the learner's panel is adding a thumbnail depicting the sender or the player's avatar, depending on whether the piece of information was sent by a team-mate or collected by the player themselves.

Finally, when an entering piece of information causes a conflict, both the new and the old bubbles are pulled to the top and flash for a few seconds. It is the player's responsibility to investigate, to alert the team, vote or choose a strategy to stop the problem or reduce the risk.

Table 5 A piece of information is interpreted differently depending on the context.

	same value	**different value**
same source	information is being repeated	information is being updated
different source	information is being confirmed by a third party	conflicting information, some of which is necessarily inaccurate

5.3 Conversational panel

On GUI, a visual panel help player to see the conversations between avatar's team : an history chat panel (see fig. 5) and a virtual memory panel (see specific section below). The chat panel displays dynamically all information exchanges between avatars. The chat panel displays the receptor avatar's role and transmitter avatar's role.

5.4 Searching and reading information

Depending on the role played inside the game and its business knowledge associated, the player has access to specific actions, documents and knowledge from the objects or from the other players.

Using point-and-click, the user can collect available information by different way:

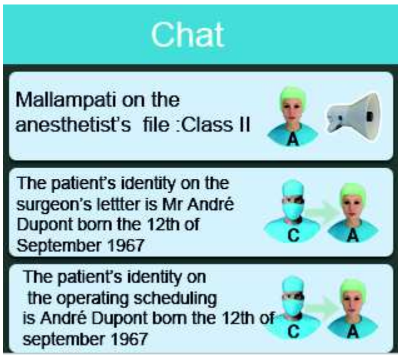

Fig. 5 The chat panel displays the chat history.

– play an action and collect an information on an object in the environment
– read and store information from a document (as pdf file)
– receive information broadcast by another member of the team
– listen someone else conversation and collect information exchanged
– ask someone else an information which is not available for its role

The next section describes the model and how all these cases were implemented in the GUI.

In the first case, the player can do an action on an object and therefore collect an information associated. But, some actions and therefore information are not directly available for a character role, so the player must ask someone else in the team to collect the information he seeks.

To collect a piece of information from an object, the player has to click on it in order to display the contextual menu. Inside the contextual menu, a list of attributes is displayed along with the interactions available on this object. In the contextual menu, the values are always hidden to the player. Positive information or negative/anomaly information is hidden as only the "inspect" labels of the attributes are displayed (see Table 4). In order to learn about its value (i.e. get the entire meaningful information), the player must click on the label and then collect the information which will be record in its virtual memory. The virtual memory of a character is represented as a box filled with draggable information bubble. That way, the game keeps a record of every information acknowledged by the player during the game session. This mechanism is essential since letting the players see and learn new information without the system knowing about it would hinder the accuracy of the debriefing.

Learning some information from digital documents as a pdf-like file needs some adjustments relative to real life. Leaving the players read by themselves information may result to a synchronization problem between the virtual memory of the character and the memory of the player. To prevent these side effects, the game needs to keep a record of every information read on the document.

So, the document contains some masked information. As illustrated in figure 6, blue boxes hide information on the document (top right: the name ; middle right: the operating site) and indicate with labels what kind of information players can read underneath. So, reading particular information on a document must result from a proactive behavior. The masking boxes hide the value of the information but their label indicates the nature of the hidden information. By clicking on it, the value of the information appears and is stored into the virtual memory of the player. The information masked may be efficient or not. These event is listened by the learning game engine.

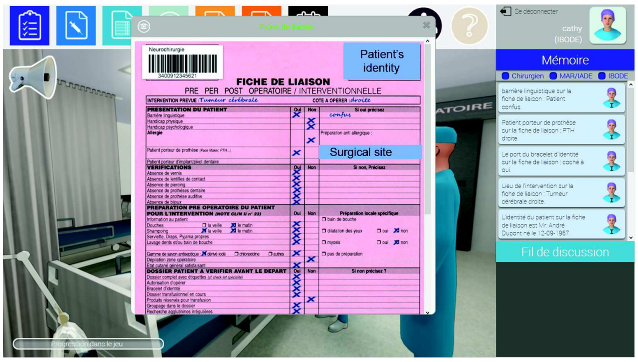

Fig. 6 Clicking a document icon on the game screen's top bar displays a realistic depiction of the document. Documents are objects that can be interacted with (changing values, ticking boxes, etc.) and from which information can be collected by clicking on blue boxes.

5.5 Broadcasting/receiving an information

Sending information is an intentional action undertaken by the players when they feel some knowledge they have acquired is of any importance to another player and therefore should be shared. Sending information to a team-mate is as simple as dragging the corresponding bubble and dropping it into to his character. In figure 7, a piece of information is being sent by a player to another character. When player A is being talked to by player B, a pop-up appears in the middle of player B's game screen. Merely clicking on the pop-up acknowledges the communication and the information bubble is placed on the memory panel. As in real life, the sender acknowledges that the message was received. A dynamic bubble alerts player A that the message was sent to player B.

A player can talk to everyone by dragging and dropping information bubble onto an icon 'loudspeaker' (top-left of the game screen).

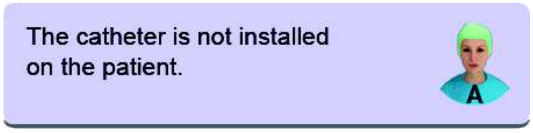

Fig. 7 An information bubble representing 'the catheter is not installed on the patient" which was sent to the player by the anesthetist nurse.

5.6 Signs and feedback to represent some implicit rules of communication

In a virtual world, all cues that exist in face-to-face conversation or speech are absent. So, we need to imagine and associate metaphors to mimic these communication implicit rules. This collaborative virtual environment contains basic features to display graphical signs and feedback to make understand that a piece of information has been sent or a question has been broadcast on the graphical sender's interface. On the other side, the receiver can see the message and who is the sender thanks to the thumbnail representing the character's role.

5.7 Asking someone else an information and answer to a question

Sending information is a proactive behavior which denotes either a good knowledge of the situation and a good experience or a too much talk-active behavior.

In practice, a significant part of the information exchange is not likely to be anticipated but delivered on request or delivered on purpose following a process application. To that end, the communication system offers a player the ability to ask some information to another player. The interaction process is similar to collect information from an object, but the value of the information is not available directly.

When player A needs to ask player B a piece of information, a list of available questions is presented to A by the contextual menu associated to B. The questions are almost straight translations of all available pieces of information in the memory of B, only put in the interrogative form using the request label (as described in table 4). At this stage, the actual value of the piece of information (positive information or negative/anomaly information) is hidden to A, since only the objects and the attribute are necessary. Information unknown to B is absent from the list and therefore unavailable for A to ask. The pending request is notified to B by a window that pops up, overlaying his game screen8, just like any other information sent. However, the pop up window including the request contains two additional buttons to send a quick acknowledgment of receipt translating their intent. "It's not my role, do it by yourself" intends to tell player A that their question is very likely to remain unanswered whereas "I'm on it" supposedly means the information is to be sent shortly. In whatever case, whether player B will indulge or not is out of the responsibility of the player alone. If the virtual memory of the player B contains the requested information, the pending information's value is displayed directly on the pop-up window with the other additional buttons "I'm on it" and "It's not my role", "do it by yourself". In this way, player B can click shortly on the bubble of information. It is the responsibility of the player B to answer the right information, something else or never answer to the question.

So, it sounds more like a conversation flowed. It could appear less binding. On the other side, the player B can also answer to the question later because he actually doesn't not know the answer to the question. In that case, an icon "'?"' (see Figure 9) relates to the matter question near the thumbnails of the character. By clicking on it, the player can select the question in a menu and pop the window presenting the question and the value of information buttons to answer.

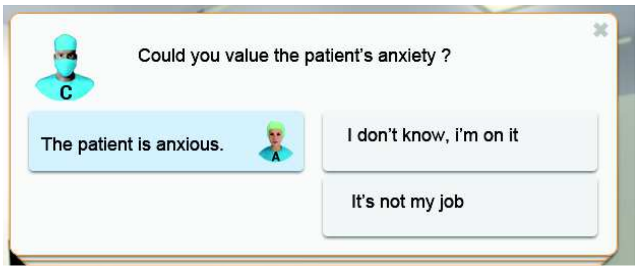

Fig. 8 A window pops and contains both the question, the generic answers and the current specific response if the character knows it.

5.8 Listening to information exchanged in another conservation

When player A listens to a conversation between player C and player B, he can pick an information value by listening and paying attention on what they talk about. The question is how to represent this kind of situation in a multiplayer virtual environment. To reproduce this situation in the game, the players have to be able to hear conversation, so a control conversation panel displays every information exchange between team members as illustrated in Figure 10). On this control conversation panel, the conversation between player C and player B appears in the chat panel. By clicking on the information bubble displayed on the control conversation panel, player A can pick and memorize the information value exchanged between other team members.

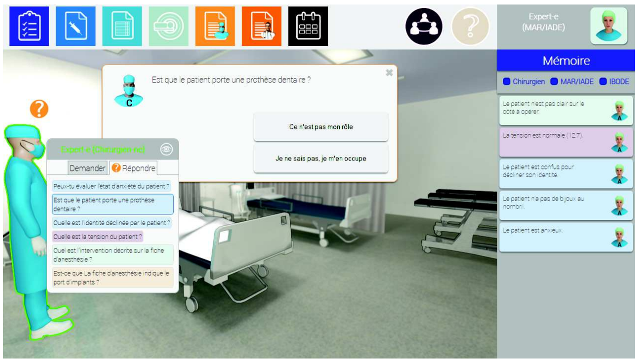

Fig. 9 A menu contains all questions awaiting an answer. By clicking on a question, a window pops including the generic answers and the current specific response if the character knows it.

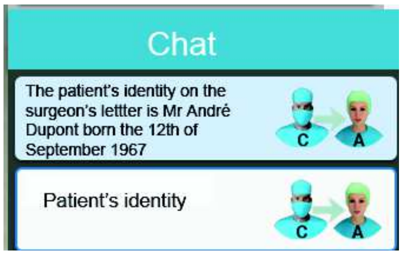

Fig. 10 A white bubble of information is displayed onto the chat panel and represents the communication between two characters. The thumbnails of the receiver character and the sender character are displayed. The value of information is hidden until the player click on it.

5.9 Voting and making a collaborative decision

In the learning context, the learning game offers multiplayer environment where each student will probably have a different representation of the situation and probably different opinions on what to do next. So, the team will have to exchange and make a cross examination of the situation. This situation is represented as a vote. The vote is a feature which offers the possibility to make a cross examination of the situation while each player can expose its opinion on a subject by arguing with information stored in the character's virtual memory.

Triggering a vote may result of a suspicion on something wrong, of a combination of difficulties on a subject or of an application of a security process.

Each one can obtain a fragment of the information about the living situation and share it with the others, or ask the team for something. By sharing and combining information, the puzzle situation is spreading for a better understanding and better bases for a decision making. All the information argued during the vote help team to build a common representation of the situation. During the collaborative decision building, all information argued are stored in the virtual memory of each player.

On one hand, analyzing the number of changing views may bring information about the level of disagreement inside the team before the final decision, the power of a leader and perhaps the team's ability to make a collaborative decision. The result of a vote could be a collaborative decision or an individual decision made by a leader.

On the other hand, analyzing the number of votes on a same subject may highlight a subject of disagreement inside the team.

Depending on their role and the context, any player can ask for opinion team on a subject at any time. A vote is composed of a selected topic and a restricted number of available answers. Players involved are requested to give their opinion on a selected topic. The final decision is under the responsibility of an identified leader depending on the topic. The leader is not necessary the player who triggered the vote.

The vote is limited in time (the time limit is set to 90 seconds) and the question asked is selectable in a list of limited and predetermined questions. During the vote, the game is paused and no action is any longer available into the virtual environment until the decision is validated by the leader. The players are free to select an answer among those available. For example : vote topic : patient operating site The question is : "Does Mr Dupont need to have surgery on cerebral tumor right?" The available answers are : "Yes", "No", "I don't know, I need to continue the check".

On GUI, when a player answers, the thumbnail of the character is displayed near the selected answer and indicates the choice of the corresponding character. In this way, the other players can see each other's choices in real time. Each player is also allowed to drag and drop information bubbles in provided spaces to argue his opinion. He stands for arguments or evidence to support his vote or convince team-mates.

At any time and in particular when the time is out, the leader player is responsible of the final decision.

Whether the final decision reflects the opinion of the majority or not, this is the responsibility of the leader player. The final answer of the leader player is the final decision. The result of a collaborative decision has an impact on the continuation of the game. It can lead either on a game over, or on an another phase of game.

6 Methodology

First of all, the principal goal of these play tests was to experiment during a real training session a digital multiplayer virtual socio-technical environment where teams could communicate : search, collect, broadcast, listen and announce information and make argued decision.

In these experiment, teams were placed into a training situation involving critical risks or near-misses. The socio-technical system is composed of an operating room with a team of medical staff and nursing staff.

During the three sessions of the experiment, every interaction within the game was computer-recorded for analysis. During every session (see Fig. 12), every student was voice-recorded. Interviews were video-recorded at the end of game session for assisting and corroborating the analysis of quantitative data. A survey was informed several days after the training game session.

The two first sessions were well-recorded by digital tracking system. But during the last game session, data collected by the tracking system tool has been corrupted and are no more workable. So for the third game session, the data were collected from video-records, interviews and survey.

To analyze the communication in the game, and to understand what was going on, the first work focused on the timeline of the different events that occurred during the game session. Then, more specific analyzes have been done focusing on particular moments for example : the beginning of the game session (the first 5 minutes of the game session), the middle of the game session (the 10 minutes at the middle of game session), the decision making building, and the last 5 minutes.

6.1 Learning environment : the virtual operating room

The learning game : 3D Virtual operating room These works are part of a IT learning project named 3D Operating ROOM. 3D Virtual Operating Room [37]

(3DVOR) is a multiplayer learning game dedicated to improve the communication inside the operating room between the surgeon, the nursing staff and the anesthetist staff. 3DVOR is a collaborative and immersive experience, where the learners are expected to follow or/and adapt clinical and paramedical tasks inside the operating room (protocols, process, checklists, etc.) from the admission of the patient until his transfer into the recovery room. Doing so, the objective of the game is to highlight the importance of sharing effective information and maintaining a good assessment of the current situation. The aim is to make the decision-making both effective and efficient, even in emergency situations. The model of the virtual environment has been described in details in [54].

3DVOR is set in a realistic environment where several locations (OR, pre- and post-operating rooms) for avatars and equipments have been carefully designed and furnished. The learning game session involves between 3 or 5 different avatar roles : operating room nurse staff, anesthetist, surgeon, anesthetist nurse. At the beginning of the game session, each player has to choose a role to play. All along a game session, the game spies on the users and records every bit of their activity in order to guide them through the scenario and deliver a debriefing at the end of the game. The interaction model proposed by the game to the users is very typical. Users are presented with a first-person perspective of the environment which realistically reflects the actual locations of the surgeon, the nurse or the anesthetist. The player is not enabled to move but the environment is seen from different point of views depending on character's role. Objects and other characters can be interacted with by means of predefined actions and interactions (open/close a drawer, power on/off an appliance, read a document, ask something to someone, and so on). Upon being clicked, an object displays a specific contextual menu listing the interactions as textual labels. Clicking on a label triggers the corresponding interaction, which is expected to have an impact on the environment and possibly entails further interactions.

Each scenario in 3DVOR has been designed to be played in standalone mode (without trainer's intervention), in supervised mode (with teacher's intervention) or in blended mode (with asynchronous trainer's intervention).

6.2 The training situation

The training scenario used for this experimentation focused on serious events as wrong patient identity, wrong operating site, patient anxiety and infectious risks. For all these events, communication default is a contributing factor. In 2009, the World Health Organization (WHO) proposed a worldwide recommendation for the use of its Surgical Safety Checklist [1] in all operative procedures. In a lot of studies, wrong surgery site, wrong patient events or wrong procedure are often reported [3, 72]. But they appeared in 1,7 to 3,6 events among 100 000 operations [72].

This scenario was designed to train people on the patient security checklist "safety checklist in the operating room" [4] that is supposed to be used to prevent wrong patient error, wrong site error... But these security rules have to be adapted when the team is facing to non-standardized situation (ie: with an unpredictable anomaly).

The situation takes place in the operating theater when the patient comes from their hospital room. The mission shown to students' team consists in preparing the patient from his arrival in pre-operating room until the end of the anesthesia procedure. The team's main tasks consist in checking if the patient is the right patient that have to be operated and if all clinical information are coherent with the patient's discourse, placing him on the operating table to move to the operating room and anesthetizing him.

The scenario provides 3 characters : a surgeon (chir), an anesthetist or anesthetist nurse (mar) and an operating room nurse (ibode). In the scenario, each character can use about fifty different professional tasks for example read arterial pressure, check if the patient wears a dental prosthesis, check if the patient wears a body piercing, prepare the operating bed, prepare the anesthesia material. . . (see table 6)

Communication with the patient is also an important element of this scenario as well. Positive communication, like presenting its role to the patient, informing him on what he will do, or telling him jokes, must be used to counter effects of the many anxiety-provoking actions of the procedure and balance the patient's anxiety within a comfort zone. The operating nurse's main task consists in checking all surgical materials and documents, checking different information by talking to the patient. For example, a good practice consists in explaining to the patient that will be done before the action was really done. Present itself to the patient before asking or doing anything is another example of good practice.

Each character has access to a limited number of documents of the patient records according to its role. Therefore the players are encouraged to communicate and to share this fragmented knowledge. For example, surgeon can read the Magnetic Resonance Imaging (MRI) but he can't read the anesthesia card. On the

Table 6 Extract from the list of available actions for each character's role

Character's role	Actions available
Operating nurse	check dental prosthesis check body piercing ask the patient to open the mouth check identity from the patient read nurse patient's file undress the patient put the heated bed cover connect the bed cover to the generator read arterial pressure check the box to confirm the patient's identity on the checklist
Anesthetist or anesthetist nurse	read the anesthetist card control the pressure points check the patient's position on the operating table check patient's ASA score put the heated bed cover connect the bed cover put on the catheter connect the catheter to the drugs put the material on the anesthesia table prepare drugs ventilate the patient
Surgeon	check patient's position on the operating table check the communication troubles check the gesture troubles read MRI check the electric scalpel control the pressure points prepare the operating table
All characters	wash hands put on the gloves read operating schedule self presentation to the patient put on the mask transfer the patient to the operating room drink a glass of water read mobile messages

other hand, the anesthetist and the nurse can't read the MRI whereas the operating room nurse can read the operating room checklist, the surgical planning... In this scenario, a vote can be triggered only by the operating room nurse on 3 identified topics : patient's identity, patient's operating site, move the patient from the operating reception room to the operating room.

Table 7 Scenario contains some anomalies to place team at risks of potentially wrong patient. The information illustrated in the figure is 'Patient.identity'.

context	label
wrist ID	unreadable
spoken ID by the patient	None (he can't say anything)
index form of anesthesia	Lemarin Pierre
surgeon's letter	Lemarin Pierre
operating schedule	Lemarin Pierre
MRI	Lemarin Pierre

To train and evaluate team 's behavior, the scenario presented in the virtual environment is filled of hidden but probable dispatched real anomalies (see Table 7). For example : bracelet unreadable, patient can't say anything because of his disease, document unfulfilled, different operating sites written on different documents...

In this scenario, the hidden anomalies are very likely to lead the team to serious events as wrong patient identity, wrong operating site... The user is also provided with the ability to inform, intervene, alert on an anomaly and stop the pre-recorded scenario to identify an error in handling the situation presented in the scenario and/or an opportunity presented in the scenario.

The main educational objective is to demonstrate the need to apply safety and security procedures but also to understand how to adapt it to prevent serious events.

All educational objectives can be presented in a tree-like structure where nodes represent objectives and leafs represent expected action or expected communication. If they are not fullfil, the risks increase until the training session was stopped. This primary objective overlap with educational objectives linked to the current damaged situation. The scheme 11 shows an example of an educational objective that is composed of expected actions and communications.

In order to assess the performance of the students, the scenario embeds a set of metrics to measure how well the standard procedures are applied and how the team reacts when they discover the anomalies and become aware of the situation.

6.3 Experiments

The experiments took place during three learning sessions. Each training session was planned for two hours at the anesthetist nurse school of Toulouse, France in March 2015. The learning game was used by a teacher to evaluate their students on knowledge of procedures, as part of the curriculum. The experiment had no impact on their grades. Three training sessions were planned

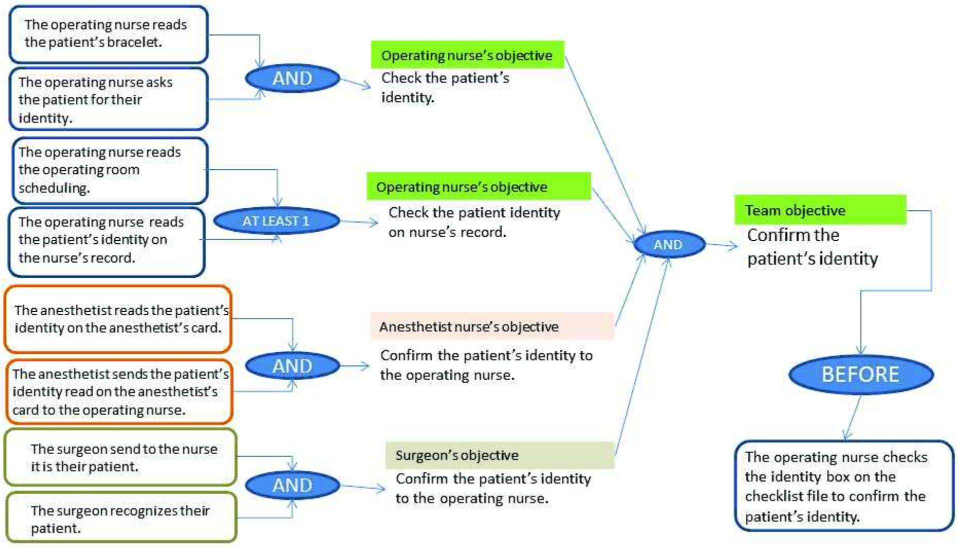

Fig. 11 The educational objectives can be represented in a tree-like structure where nodes represent objectives and leafs represent action or communication.

the same day with different teams. A different team of students was involved in each game session. Each team was composed of 6 students (both men and women). In each game session, the same scenario was suggested to students' team. The teacher prevents students not to communicate information to the other team before their game session. Each game session took place the same day in the same room. The students were all together with their teacher in the same classroom. One dyad is placed face to the two other pairs of students.

The teacher distributed character's roles to students according to criteria like ability to communicate in real life and cleverness with digital environment. A mark was placed on the desk to identify character's role. Students sit in front of a computer. Considering that all the learners were inexperienced on anesthesia and surgery tasks, the teacher asked them to pair-up so that each team would be composed of 3 teams of 2 students (see Fig. 12). Each pair would then have to play a role in the game: the surgeon, the anesthetist and the operating room nurse. A pair of students had to play the role of surgeon, another pair played the role of operating room nurse and the last one played the anesthetists role.

The rules of the experiment were clearly stated at the beginning of each session. Spoken dialogue was not allowed outside of the pair as only the game communication system must be used. Spoken dialogue within a pair of student is allowed. Teacher chose not to give time for students to get acquainted with the game environment but the interactions provided in the game were all presented with short video by the teacher before the game session starts. The teacher used the supervisor console to watch in real-time every action, every information exchange between character's during the game session.

Fig. 12 In each game session, three groups of two players and the trainer take part of the learning session. While the learners are playing, the trainer (at the bottom right) supervises the game in real time and uses the supervisor's tools to take control of the session when necessary.

In the following sections (section 7 and section 8), the analysis are conducted according to 2 axes: The first one focuses on teamwork exchanges based on: documents access, broadcasting, listening, announcement, request and answer. The second one focus on decision making and team situation awareness. The team situation awareness is based on sharing a mental model of the situation. Without information exchanges inside the team, each one can have a narrow vision of the situation and make unsuitable decision.

7 Results on communication system

The system was designed with advanced user-friendly features, including interactive broadcasting, listening, announcement, request and answer systems. The first step consists to observe the teamwork timeline to make sure that the communication system is operating and readily useable. Checking this point, individual representations of the situation should be built during the session.

7.1 Global view of the teamwork

The game session lasted near one hour for the first one and twenty minutes for the second one. A part of analyze presents how all features were used all along the timeline of the game sessions. Data analysis and graphics (see graphics on figures 13 and 14) show that every feature was used all along the training session. During session 1, we can observe a period of team's inactivity which corresponds to a break initiated by the teacher. The teacher took a break to help students to pass over a difficulty to make good decisions regarding to the socio-technical context. For every session, the communication started between the team members during the first minute of game session. The dialogue is initiated between 2 players most often by a request. During the first minutes of the game session, students discover that doing action makes sounds and they have fun with it.

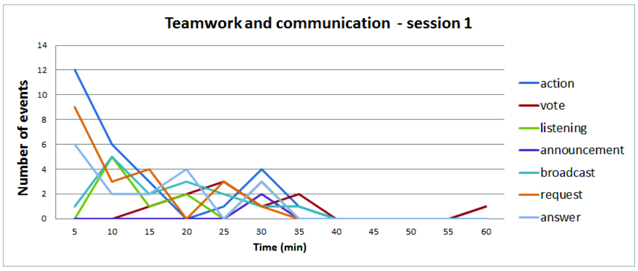

Fig. 13 Global activity grouped by features - session 1.

Graphic on figure 15 compares data of 'search, collect and read' features between session 1 and session 2. These curves make clear that the strategies of each teams were really different when they began to play (see subsection below for further study).

The other part of study comprises determining the division of responsibilities between character's roles. The graphics (see graph.16 and graph.17) shows the global activity grouped by character's role. During the first game session, the main activity of the team focused on tasks and actions inside the environment. 454 events

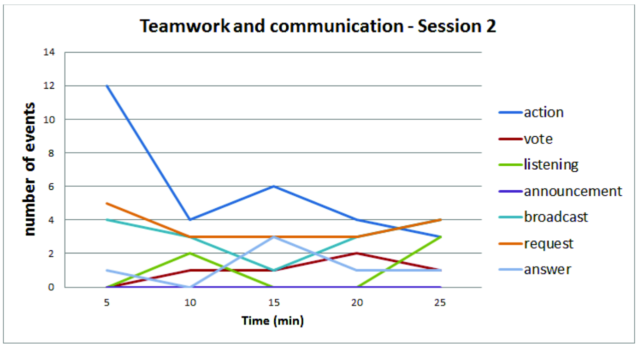

Fig. 14 Global activity grouped by features - session 2.

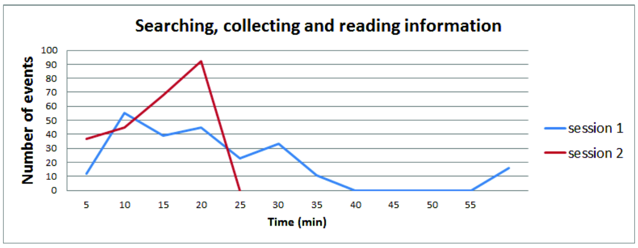

Fig. 15 comparing global seeking activity between session 1 and session 2.

were recorded by the tracking system while the first team played. During the second one, both activities 'search, collect and activity inside the environment' and 'question/answer' are well-represented. 670 events were recorded by the tracking system during the second game session .

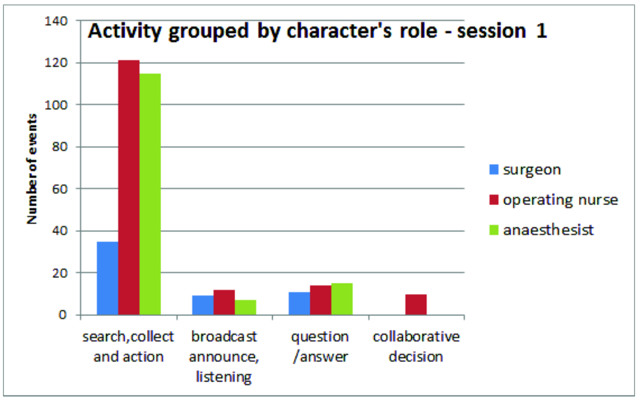

Fig. 16 Global activity during game grouped by characters role - session 1.

Based on these figures, several observations and hypotheses can be formulated. The quantity of information collected from objects is significantly higher than other related interactions like transmissions or requests. This behavior denotes a systematic information scavenging of the environment by the learners and points out that on several occasions, the team may have temporarily lost the track of the scenario. This problem is

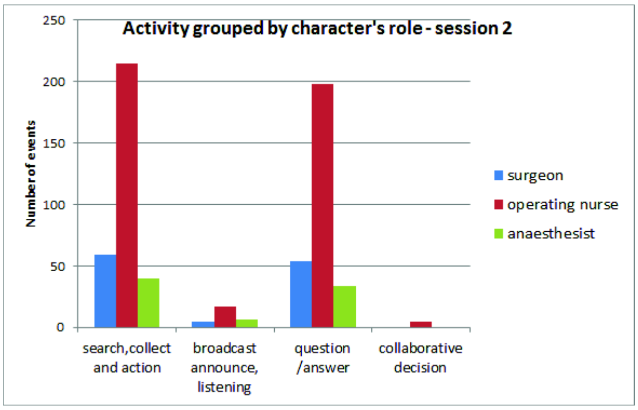

Fig. 17 Global activity during game grouped by characters role - session 2.

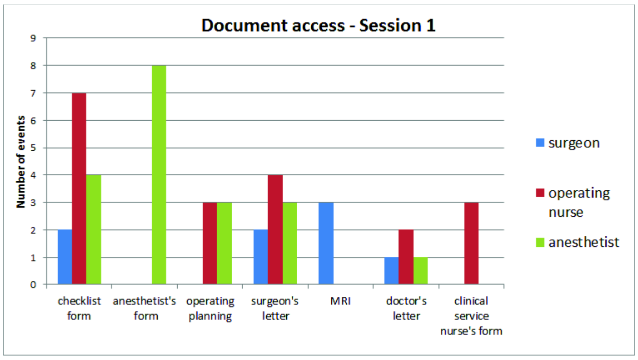

Fig. 18 global document access during game session 1.

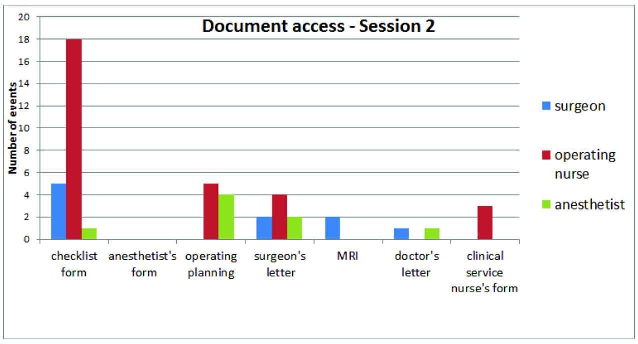

Fig. 19 global document access during game session 2.

independent from the communication system and can be explained by the fact the learners in this experiment were not experienced surgeons, anesthetists and nurses but students.

In a general way, the analyze of data expresses a strong involvement of all the learners inside the game, which is confirmed by the recordings showing enthusiastic and lively behaviors. No main interaction has been left unused, which indicates the different interactions seem to have been understood by the learners. The collaborative decision feature has only been used by the nurse because it is the only character who can trigger a vote on this scenario.

7.2 Feature "collect information on documents" analysis

Histograms on figures 18 and 19 count how many times each document has been accessed by each character's role. Some documents were unavailable to specific roles to reflect the fact that for instance the anesthesia record can only be read and understood by the anesthetist. On average, the checklist form had been read 6,2 times, the anesthetist form had been read 1,3 times, surgical planning 2,5 times, MRI 0,8 times, doctor's letter one time and clinical department nurse form one time.

In the figures 18 and 19 the inaccessibility is not mentioned. But this specific point can explain why some documents were not readable by students. Unlike the information inside the environment (see paragraphs above), information from the documents were accessed parsimoniously. This indicates that the learners were well aware of the interest and the utility of this information and therefore the documents were only accessed on purpose.

7.3 Features "broadcast", "listen" and "announce" analysis

The graphical data 20 illustrates a global view of the activity according to broadcast, listen and announce information to the other characters.

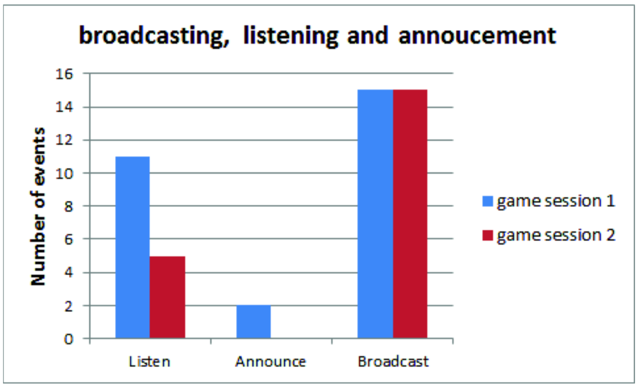

Fig. 20 global view : Use of broadcasting, listening and announcement.

The "talk to everyone" feature was very scarcely used and perhaps most of the learners could not figure how to use it properly and safely preferred the one-to-one communication scheme.

7.4 Features “request/answer” analysis

The first 5 minutes of game session 1 Since the first minute, a question were asked to a member team. At the beginning, 9 questions were asked and 7 answers were sent to respond. Every answer sent by the pop-up channel was 'I don't know, I will do it' and just one answer was sent by drag and drop under the character's asking.

The dialogue is engaged between every team member.

Data collected for the first 5 minutes in game session 1
anesthetist ↔ operating nurse : 2 different questions asked
surgeon ↔ nurse : 2 same questions asked quasi successively
anesthetist ↔ surgeon : 1 question asked
operating nurse ↔ anesthetist : 3 same questions asked quasi successively

The first 5 minutes of game session 2 Unlike to the first team, this one began to ask a question during the second minute. For the second team, 6 questions were asked and 6 answers were sent. Every question was answered very shortly and just one was 'I don't know, I am on it'. The delay between the question received and the answer sent was shorter and shorter: 10 sec. at the beginning and less than 3 sec. at 5th minute. Like the first team, every team member was involved into the dialogue pair-to-pair (operating nurse↔anesthetist, surgeon↔anesthetist and surgeon↔operating nurse).

Since the beginning, the strategies of the teams 1 and 2 were different. The team 1 communicated at first without having collected any information. The team 2 collected at first information then asked questions. As players know some information, they are able to answer faster. So, the response's delay were shorter at the beginning of the game session 2 and the information sent were relevant because all the wanted information have been sent to the applicant.

But, for all of them, from the beginning of the session, models of interaction proposed around the questions/answers have been used.

7.5 Synthesis

The data analyze confirms the hypothesis that the designed communication system is operative and user-friendly. This system endeavored to offer the simplest and most intuitive way for several learners to acquire and share knowledge in a virtual socio-technical environment. The first experiments demonstrate that the 3 teams of students use it easily even if some features like 'Talk to everyone' or 'Listen' were scarcely used. The collaborative decision period could be seen as a period while player decide something on a specific subject, but it also appears like a moment while players exchange information by arguing with knowledge. Checking this point, each individual may have built their own representation of the situation. At this step, it is impossible to know if they share the same representation.

8 Results on team situation awareness

In this second step, as the communication system was enough useful to exchange information between team members during virtual teamwork, it implies that each individual should have his own representation of the situation as pieces of information have been collected. But, even if they knew some information, they might not be aware of what is going on and might have built a correct or erroneous representation of the situation.

The global educational goal is not to agree each other on an answer but to facilitate professional expression about their individual point of view. This behavior could help leaders to manage and make better decision listening all teammates' point of views. The "‘vote”’ feature should allow to reveal dangerous behavior. The behaviors that consist to unsay things, or non-formulate disagreements can lead to accidents. Most of the time, unsaid things or disagreement are not formulated in real operating situation. Professionals fear to express their disagreement because they fear of their hierarchy or their colleagues' judgment if they are wrong or if they seem not to control the situation. Compelling professional to express their point of view in a virtual professional context could help to reveal and correct dangerous behavior before they have to manage similar situations in real life.

Actually, the question concerns the team situation awareness and how they lead collaborative decisions.

8.1 Feature “vote” analysis

Overall, the voting system has been used: 10 votes during the session 1 and 5 during the session 2. On average, the team of learners took 7,5 collaborative decisions (votes) per session.

Session 1: The first vote appears at the 10th minute. Of the first vote, all the players are involved in positioning arguments and validating their response. The feature “remove argument” was less often used. Sometimes, the leader didn't wait for all choice validation to make a decision.

During the whole session, 6 votes are triggered on the topic "patient transfer to the operating room", 3 votes are triggered on the "patient identity" topic and 1 is triggered on topic "operating site of the patient" 8.

On average, 1,6 values of information were pushed by each team member to argue an opinion during this decision-making time. The number of vote occurrences can lead the analysis either to a team disagreement or to an unquestionable doubt. The team suspects that something was wrong with the patient even if they try to apply safety and security process.

Table 8 collaborative decision-making

subject	time (t_0+)	decision result
transfer patient to OR	11'	No
patient identity	15'	Yes
transfer patient to OR	17'	No
patient identity	20'	No
transfer patient to OR	23'	No
transfer patient to OR	24'	No
patient operating site	30'	continue to check
transfer patient to OR	32'	No
transfer patient to OR	54'	Yes

The observation can be made that between the 2 last votes, a long time passed. In fact, the teacher stopped the game session and help them to pass over the team's difficulty to make the right decision. So, all team members voted to transfer the patient to the operating room. The same difficulty appeared both in the second and third session and the teacher also stopped the session to help them to progress on the scenario.
We are going to focus on the vote concerning the identity of the patient. The question can be presented as: "Is Pierre Lemarin the right patient?"
The first time, the vote is unanimous. All the members of the team vote without modifying their opinions and put some pieces of information as arguments (surgeon:1, anesthetist:2, operating nurse:3). The surgeon argued with the only compelling argument: "I recognize my patient".

But, 5 minutes later, one of the players proposes a new vote on the same subject. Meanwhile, each had collected new values of information and perhaps has a new representation of the situation. The operating nurse is the first one to vote and vote for "Yes" arguing with three values of information. Among its argumentation, the main one "The surgeon recognizes the patient". Then, the surgeon votes "Yes" as the first time and positions the same only compelling argument "I recognize the patient".

Then, the anesthetist votes "Continue to check" and argues with an information which shows an anomaly found on the patient bracelet. Then, the operating nurse has a change of mind and votes "No". She/he removes then all the arguments and adds two new ones which should not hold faced to the surgeon's one. The operating nurse who is also the decision leader, decides alone to close the vote with "No". Finally, the operating nurse decides not to trust the surgeon although he is the only one to detain the best vision of the situation. Furthermore, the surgeon tried to share his vision with the team.

2 minutes later, the nurse launches the same vote on same topic : "patient identity". At this time, the nurse and the anesthetist chooses to say 'No' again and the surgeon says 'Yes' again. In the classroom, some students tried to express their dissatisfaction with non-verbal communication by gesturing, by expressing that they take a step back for example taking support on the back of the seat.

We can admit that characters who know the relevant pieces of information in their virtual memory and use it during a vote session confirms that they are aware of the situation.

The fact is that the operating nurse didn't want to trust the surgeon. This reason was pushed during the debriefing discussion with the teacher. The students explained that the surgeon was generally out during the arrival of the patient near the operating room. In that case, he prefers to check asking a nurse working in the clinical department. The teacher explained to students that in this specific case, the nurse would trust the surgeon because it is possible that any other nurse can come to confirm the identity of the patient.

Video records show irritated gestures from the learners on these occasions. Interviews conducted after the sessions have revealed the learners wish they could have used some chat system ultimately. In this conflict moment, they would have liked to use spoken dialogue or text-chat to succeed to convince the other members of the team.

Both in the first and third session, a point of disagreement on a specific subject appeared too. This point of disagreement is independent from the communication system. The subject of disagreement can occurred at anytime, on any subject depending on the experience of the team. To solve it, an experimented leader knows how to do in a critical situation. Here, the deadlock can not be solved by the leader. This can be explained by the fact that the leader was not an experienced surgeon, anesthetist or nurse but student.

It was observed that during a vote, the learners tended to argue much more than in real life, and they clearly failed to identify the most relevant information likely to rest their case unquestionably. They were really affected not to success to get a common agreement on what to do in such situation. As a result, deadlocks were reached on some occasions and the intervention of the trainer was necessary. This inactivity period is observed too in graphic13.

The communication system experimented highlights the difficulty to make a collaborative suitable decision. It made possible building a common representation of the situation. Using this system, the team experimented how hard it is to get the agreement of everyone to make a decision or to decide something by trusting someone who seems to be the less qualified even if he is the one to argue with an uncontested evidence.

8.2 Synthesis

The experiments shows that even if the information exchanged are facts, team members have shared many pieces of information. And, all anomalies hidden have been found and exchanged between team members.
Pieces of information were exchanged either by arguing while the decision-making period or by using communication features as broadcast or asking/answering system. The discussions during the debriefing periods were lead by the teacher and confirm these results. The communication system was well used to identify failures, evaluate causes and learn appropriate actions to improve performance in the future.
Relevant pieces of information have been put as an argument during the vote session that could be a meaningful point to conclude that they are well aware of something was wrong. Arguing during the vote session, they build and share a common vision of the situation.

These works have demonstrated that mechanisms implemented in this virtual environment offer the possibility of strong communication and provide a decision-making system that enable the team to build a common representation of the global situation. In a more general context, the communication system revealed capable to raise a matter even if the team was incapable to solve it because of ingrained conflicts.

Points of disagreement on a specific subject appeared both in session 1 and 3. When facing adversity, some learners were clearly and firmly disagreeing with the rest of the team.
Then, two sides effects were observed:

- the first behavior : some members refuse to communicate by systematically answering “It’s not my role” to every question
- the second behavior : the leader tries to convince the others by triggering votes on the same subject close together.

The students get caught up in the role of character and gradually become involved in the game. But during the disagreement period, some students express their disagreement with the other members by using the generic answer button “It’s not my role” and with irritated gestures. The restricted expressiveness of the generic information buttons have been used to express the sense “I don’t agree with you”.

These points of disagreement are independent from the communication system. The subject of disagreement can appear at anytime depending on the subject and the socio-technical context. The communication system facilitates to share a common vision of the situation inside the team, but not to make the players agree about the most suitable decision to make.

The leader is the only responsible of the final decision. It is the leader’s responsibility to vote following the required majority or to vote according to the most experimented or qualified member. Sometimes, the leader bases their decisions on their own conviction. This behavior can lead to inadequate decision-making regarding the real living situation.

The communication system makes possible the cross examination on a subject and shows to each team members that sometimes there are different points of view on what to do even if a common representation of the situation is shared. The use of voting system shows the difficulty to trust anyone who seems to be the less qualified to decide and the difficulty to make the best suitable decision.

It actually took one hour for a team to agree on each other. It could appear as not efficient but it is not. The scenario does not aim to make them agree on what to do but it provides conditions to express themselves on what to do and place the leader face to their responsibilities. The tutoring system failed to recognize a persistent disagreement or a leader’s failure that could be identified.

On the other hand, the system could be improved with a new feature that compels the leader to make a decision. In other terms, the environment should provide firstly a discussion system and secondly a decision system both based on the voting features. The discussion system would propose Yes, No and a non-answer as Continue to check whereas the decision system would not propose a non-answer but just Yes or No. Perhaps, these new features will compel the leader to make a real choice and assume their manager role.

9 Conclusion

In this paper, we have presented an innovative communication system designed to be used in fully digital educational environments. It is based on information tags reflecting states or facts about the virtual environment and that can be manipulated by the players thanks to graphic interactions. The communication system presented in this paper aims to control the conversation topics and facilitate the conversation by implementing some implicit conversation rules and proposing decision making features. It focuses the players onto seeking out information, sharing it and using it for making decisions.

Unlike chat rooms, this communication system combined with a contextual action system facilitates the game monitoring the conversation and use this knowledge to keep the teammates and the trainer informed on their achievements. As in a chat room, the notification and feedback systems concerning the "'question/answers"', "'broadcasting'" and "'voting'" features help the users to maintain an enjoyable conversation flow. Although it is not as expressive a way to communicate as chatting or voice-chatting, the system has been designed so as to enable the game to understand the exchanges between the players and to use that knowledge for debriefing the team, or at least facilitating the task of the trainer. Indeed, the communication between the team members is tracked, logged and used for displaying to the learners a personalized feedback in real-time or a reliable assessment of their performance at the end of each training session. Experiments were conducted in a healthcare training context, using a collaborative scenario taking place in a virtual operating room and dealing with risks related to operating the wrong patient or the wrong site. Such risks are likely to be eliminated provided the team members communicate with efficacy. Therefore, the proposed scenario is perfectly suitable for testing the communication system. Analyzing the results allowed for the following findings. Firstly, data and video footage recorded during the game sessions have clearly demonstrated the successful appropriation by the learners of the various graphic interactions at hand to communicate. The data show that information was easily read, "listened" and shared by the learners, and that questions were purposely asked and answered. Post-game interviews confirm that the game has received a positive welcome from the audience and the communication system was deemed user-friendly by the learners, even though some features were scarcely used like talking to everyone at once or collecting information from an overheard dialogue. Secondly, the data show that the communication system has successfully enabled each learner individually to build their own representation of the situation. Precisely, each learner has been led to seek out the potential failures in the protocol and share every anomaly upon being detected. That way, common perceptions of the situation were built and maintained collectively during the session. Latent mistakes were therefore made explicit, identified and for some of them corrected before happening. Thirdly, the voting system has reached its objectives as well. By enabling the cross examination of a subject by several players in real time, the voting system has stressed the fact that, in spite of everyone having the same understanding of the situation, different points of view on the action to carry out may be exposed, and coming to an agreement was not always possible. Particularly, the votes have highlighted the reluctance to trust or endorse the decision of anyone seemingly less qualified, and the difficulty to assume the role of leader.

In conclusion, conflictual situations are likely to thrive in a collaborative working or training task because they are inherent to the socio-technical context itself, to the team's experience, or they root on many other factors beyond the team's control. The role of the communication system is not to provide an utopian automated way to solve those points of disagreement but to make them explicit for the learners as a team to identify them and learn to prevent their appearance. In every aspect of this challenge, we claim that the communication system described in this article has succeeded.

Solving conflicts or persistent disagreements, however, has often required the intervention of the trainer. Therefore, future work will aim at conducting further experiments dedicated to better understanding collaborative decision making and improve the system towards assisting the learners solving the conflicts and breaking the deadlocks. For example, when the same vote is repeatedly triggered despite the irrefutable solution has been evidenced, the system should step in and figure a way to alert the learners, either as a feedback or a "game over". This inability to get past the trap of voting over and over on the same topic could also be overcome by adding the ability to attribute a weight to an argument.

Future work will enhance the collaborative learning environment with a 3D environment and a task completion system so as to improve the virtual experience of collaborative teamwork in a socio-technical context.

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