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Catherine PONS LELARDEUX

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Real-time Virtual Collaborative Environment Designed for Risk Management Training: Communication and Decision Making *(Environnement virtuel multi-joueurs temps-réel pour la formation à la gestion des risques: Communication et prise de décision)*

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Directeur(s) de Thèse :
M[r] Jean-Pierre Jessel Professeur Université de Toulouse UPS

Autres membres du jury :
M[r] Stéphane Natkin, Professeur, Conservatoire National des Arts et Métiers, *(Rapporteur)*
M[me] Elise Lavoué, Maître de Conférence, Université Jean Moulin Lyon 3, *(Rapporteur)*
M[r] Pierre Lagarrigue, Professeur, Université de Toulouse, INU Champollion *(Examinateur)*
M[r] Vincent Minville, Professeur Praticien Hospitalier, CHU de Toulouse, UPS *(Examinateur)*
M[r] Damien Djaouti, Maître de conférence, Université de Montpellier, *(Examinateur)*

Résumé

Communication et prise de décision dans un environnement virtuel multi-joueurs temps-réel destiné à la formation à la gestion des risques

Les facteurs humains figurent parmi les causes originelles de trop nombreux accidents, dans les transports, l'industrie ou encore dans les parcours de soins. Dans ces contextes socio-techniques complexes et dynamiques, le risque de survenue d'incidents est permanent. La formation des équipes interprofessionnelles à la gestion des risques dans un environnement reproduisant fidèlement le contexte professionnel est un enjeu majeur. La motivation de cette thèse est de proposer un environnement virtuel multi-joueurs destiné à la formation à la gestion des risques liés à des défauts de communication ou de prises de décision. Pour cela, une méthode de création de scénarios interactifs destinés à la formation à la gestion des risques a été présentée. Un système de communication, un système collaboratif de prise de décision et un modèle de description d'objectifs complexes composés d'actions, de communications et de décisions sont présentés. L'environnement multi-joueurs interactif s'appuie sur cet ensemble cohérent. Ces systèmes et modèles proposés octroient une relative liberté aux équipes pour gérer la situation professionnelle présentée au sein de l'environnement virtuel. Ils permettent aussi le contrôle de la situation pédagogique dans son ensemble. Une méthode à forte valeur d'innovation a aussi été proposée pour structurer le débriefing d'une formation à la gestion des risques. Cela permet notamment d'automatiser la production de débriefing personnalisé, individuel et collectif à l'issu des séances de formation.

Mots-clés : environnement virtuel collaboratif, scénario, formation à la gestion des risques, communication, échange d'informations, prise de décision collaborative, argumentation, serious game, environnement multijoueurs.

Abstract

Communication and Decision Making in a real-time Virtual Collaborative Environment Designed for Risk Management Training

Many accidents in transport, industry or healthcare result from a causal chain of events where inadvertent human errors have not been corrected in time. In such socio-technical and dynamic systems where complexity and unpredictability widespread, training teams to risk management in real-life like situations is crucial. This thesis aims to provide a virtual multi-player environment designed for inter-professional team training to risk management. To that end, a method to design risk management interactive and controlled scenario has been described. A communication system, a group decision making system and a team tracing model have been created. They all together enable the virtual team to be free enough to manage the educational situations. These coherent and innovative environment allows us to control the team activity and automate the edition of a personalized, individual and corporate debriefing at the end of a team training session.

Keywords: virtual collaborative environment, interactive collaborative learning, risk management training, serious game, collaborative decision making, argumentation, communication, information exchanges, multiplayer environment

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"Success is not final, failure is not fatal: it is the courage to continue that counts."
Winston Churchill

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Part I

Context, goals and challenge

Chapter

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Global introduction

1.1 Context

During several decades, the society was the witness of a large variety of accidents on different industrial contexts as transport (aeronautic, aerospace, shipping. . .), nuclear, healthcare, mechanical, chemical, electrical industry. . . . As everyone would like to live in a safer world and learn from its mistakes, many programs on risk management and disaster reduction were developed to analyze, prevent and avoid some serious events or accidents. Professionals and researchers from different disciplines investigate the near-misses, serious events and accidents aiming to seek out the failures, technical or human errors on these events which have led to a disaster. The proceeding for identifying the errors or evaluating its causes aims to highlight the main contributing factors, particularly human factors such as communication default, stress, fatigue, human-machine interface problems. . . Nowadays, it is well known that accidents or disasters are not caused by a single mechanical or human failure. Most of them do not happen in isolation but they are the result of chain of events. Researchers proposed to classify accidents with three type of accident models: sequential, epidemiological and systemic [Hollnagel2004]. A sequential theory of accident causation had been grasped by most of researchers in the field of human error. This theory from Heinrich's axioms [Heinrich+1931], Bird's Domino's theory [Bird1974] and Reason's [Reason1990][Reason1990] 'swiss cheese model'.

Consequences of an accident are multiple: loss of investment, people injuries, contamination of environment. . . The chain of successive events that build the trajectory to an accident is shaped by the human activity. Most of the time, when flow of events takes away from an expected trajectory, the main objective is clearly not completely achieved and the probability that the worst unpredictable accident appears increases. In many domains as transport, manufacturing, healthcare and process industry, there are lost of examples of incidents, disaster, near-misses, serious events or accidents whom one of the root causes is connected to human activity.

Amalerti et Hoc [Amalberti+2005] classified different human activities or industries according to the level of exposure of catastrophe or deaths.

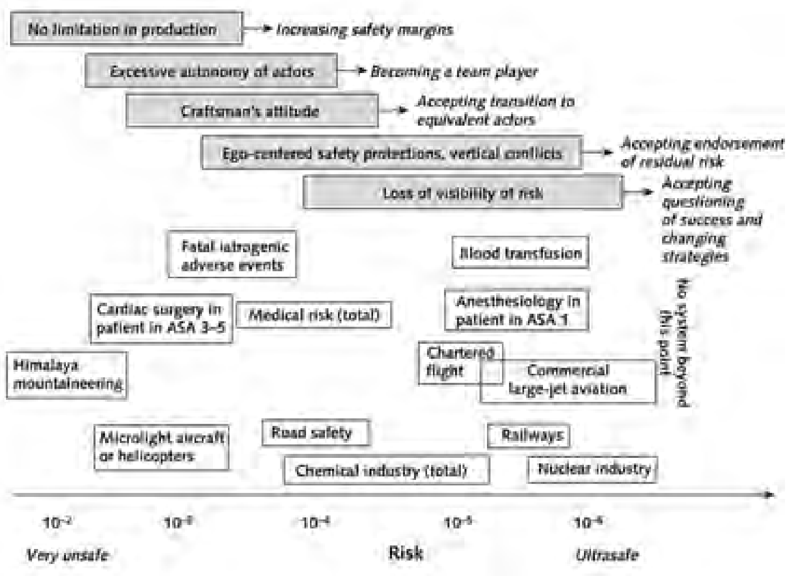


Figure 1.1 – Average rate per explosure of catastrophes and associated deaths in various industries and human activities.

Many studies have identified human errors contributing to incidents, accidents or disaster in domains like aviation, rail industry, medical, road, nuclear and chemical industries[Shappell+2012][Glendon2009][Malakis+2010][Straeter+2002][Wilson+2006]. The last three subsections present some examples from domains where academic research and experts studied accidents or major disasters for which communication default or wrong decision had been identified among the root causes.

1.1.1 Example: the aviation context

The aviation context is one of the most advanced studied system in terms of safety and risks management. Even if aviation accident is fortunately rare, each time, experts investigate to rebuild the chain of events that leaded to the incident. The International Civil Aviation Organization (ICAO) and the Commercial Aviation Safety Team (CAST), which includes Government officials and aviation industry leaders, propose a taxonomy which is used to classify the aviation occurrences (ie accidents or incidents). In this taxonomy, human factors, failures, technical damages, wildlife or natural weather conditions are listed as possible contributive factors.

Using this taxonomy, the Boeing company analyzed their flights between 2006 to 2015 and the three first categories of fatalities are loss of control in flight, runway excursion and controlled flight into or toward a terrain.

In Europe, the European Saefty Agency (EASA) publish in its annual report in 2016 that among the accidents happened in 2015, the only fatal accident in the category ''aeroplanes'' involving an EASA MS operators was the Germanwings accident on 24 March 2015. It can be observed that there was a higher number of non-fatal accidents involving EASA MS operators in 2015 than the 10-year average, with 24 compared to the average of 21.8 over the previous 10 years[Agency2016].

In this annual report, the EASA mentions that 3 083 "'CRM and communication"' incidents were listed in human factors against 1718 in "'personal readiness and crew impairment"' and 34 for "'Flight crew perception and awareness/decision making and planning"'.

On one hand, the relationship between organization management, the safety management systems and the professional practices are explored from many decades through the deployment of different measures and methods[McDonald+2000][Atak+2011][Wiegmann+2005].

On the other hand, the aviation companies tracked any element that could help them to increase and improve safety. Between 1959 and 2015, the Boeing Company tracked aviation accidents and showed that 53 percent of all commercial airline fatal accidents occurred during the takeoff and landing phases of flight[Boeing2015]. The figure 1.2 represents the percentage of fatal accidents and onboard fatalities during each phase of a flight. But the flight phases are not the only crucial stage for aviation safety. Aircraft maintenance is also generally regarded as a crucial step[McDonald+2000][Atak+2011].

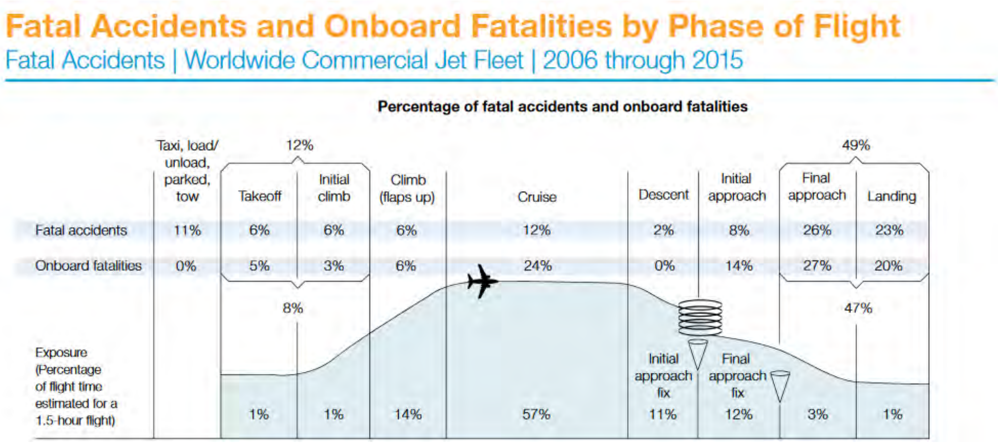


Figure 1.2 – Fatal accidents and onboard fatalities by phase of flight.

The recent example of Emirate Company illustrates the critical phase of landing. An accident on Emirates company happened in July 2016 to a Boeing 777-300 which touched the ground with their belly while landing and ignited. The Australian Transportation Safety Bureau analyzed 75 fatal airplane accidents which occurred between 1988 and 1990. They mention that the three most frequent occurrences were loss of control, collision with terrain and wire-strike. The most common pilot factors relates to poor judgment and decision making [Bureau1996].

The Flight Safety Foundation - a worldwide organization since 1947 - develops recommendations to reduce approach and landing accident for the safety in aviation and aerospace industry. According to this foundation, “there is a general agreement that human error is involved in more than 70 percent of aviation accidents”[Foundation2000]. In may 2001, the Joint Aviation Authorities (JAA), a co-operation of most European civil aviation regulatory authorities (created before EASA in 2002) mentions that 70-80 percent of accident are due to human factors. Management safety experts in aviation use some tricks to open discussion into human errors in aviation situation. For example, Gordon Dupont, from Transport Canada used since 1993 the dirty dozen concept to open discussions on safety and human errors. The dirty dozen concept refers to the twelve most common Aviation Maintenance-related, Human Factors causes of errors: Lack of Communication, Complacency, Lack of Knowledge, Distraction, Lack of Teamwork, Fatigue, Lack of Resources, Pressure, Lack of Assertiveness, Stress, Lack of Awareness, and Norms. Different studies [Endsley+2000; Fracker1990; Sarter+1991], since 1988, have shown the role of human factors and especially the role of the situation awareness in the aviation accidents. Hartel et al [Hartel+1989] explained that a lack of communication was the lead causal factor in a review of 200 aviation mishaps.

Fortunately, in spite of all unpredictable and possible events that can occur during the take-off, the flight and the landing, very few accidents happen comparing to the number of flights all over the world.

1.1.2 Example: the healthcare context

Healthcare is another field for which human error can lead to dramatic consequences. Numerous investigators present this 10^{-4} risk for accident as an extrapolated average value in health care [Gaba2000][Leape1994]. Adverse events can occur at any phases of the patient care especially in hospitals but 65 percent of adverses events are linked to surgery [Zegers+2011]. Beyond the human tragedies, the costs have been estimated between \$17 billions and \$29 billions per year in United States[Kohn+2000]. The rate of fatal adverse events among hospital patients is much greater but it depends on the domain [Kohn+2000]. In obstetrics, anesthesiology, or blood transfusion, the risk for fatal adverse events per exposure is less than 10^{-5} [Amalberti+2005]. Conversely, surgery has a total rate of fatal adverse events of almost 10^{-4} [Thomas+2000]. In France, 9.2 adverse serious events occurs in surgery while in the same time 4.7 occurs in medecine [MotyMonnereau2009].

Some examples of surgical serious adverse events as wound infection, anesthesia injury, wrong-surgery-site, wrong-patient, retained surgical items, surgical fires, patient fall... Hempel et al. [Hempel+2013] have been referenced as consequences of human errors. In "‘To err is human"’[Kohn+2000], different types of errors are referenced as :

- diagnostic: error or delay, failure to employ indicated tests, use of mutmoded tests, therapy, failure to act on results of monitoring or testing...
- treatment: error in performance of an operation, procedure or test, error in administering the treatment, error in dose or method of using a drug...
- preventive: failure to provide prophylactic treatment
- others: failure of communication, equipment failure...

A study conducted in 21 Dutch hospitals in 2004 [Zegers+2011] aimed to determine the presence of adverse events during hospitalizations and to consider how far they could be prevented. The results showed that surgical adverse events occurred in 3.6 percent of hospital admissions and represented 65 percent of all adverse events. 41 percent of the surgical adverse events was considered to be preventable.

In 1999, Gawande et al[Gawande+1999] studied 15,000 randomly medical records concerning patients from Utah and Colorado Hospitals in 1992. Among adverse events, 54 percent of surgical adverse events occurring in industrialized countries are considered as preventable events. Many studies show that human factors are most often listed among the multiple causes of an accident or a near-miss. They also point that the most current root causes of adverse events in the operating room is due to a communication problem [Halverson+2011; Kohn+2000; Lingard+2004]. 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 [Pennsylvania Patient Safety Authority2007]. 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 [Joint Commission2008] that 64 percent of root causes of sentinel events (3548 adverse events reported) involved communication default between 1995 and 2005.

In France, the national ENEIS report, edited in 2009, aims to publish analysis on adverse events connected to cares. 6.2 serious adverse events occur in 1 000 days of hospitalization ie: approximatelty one serious adverse event each five days in a clinical service in charge of 30 patient’s beds. This report pointed that among the human contributive factors: 27.6 percent concerns the human professional failures, 26.4 percent concerns the insufficient supervision of team’s members, 24.1 percent concerns the communication defaults between professionals.

In the operating room, the good operating achievement essentially depends on the dynamic information exchanges [Plasters+2003]. The miscommunication is the clincher of near-misses and adverse events[Hempel+2013].

1.1.3 Example: the railway context

The transportation industry is another domain where human errors can cause fatal accidents. Some research focused on railway incident occurrence that involved communication default [Murphy2001][Shanahan+2007].

As in aviation, there is a large quantity of research describing and classifying the nature of errors associated with one particular type of railway incident. The errors related to "‘Signals passed at danger"’ have been categorized from a range of different perspectives including behavioral and cognitive or information processing [Wright2000].

Wilson et al [Wilson+2006] revealed that the critical aspects of the railway safety are the communication, shared planning and conducting briefing, all central to a collaborative work. As in aviation, the teamwork is virtual by means that they are not all located in a same place and their gangs are mobile. The recent research in applied ergonomy focused on the mental workload of signalers [Pickup+2005], team-working and situation awareness [Bristol2004], reasoning [Jorna+2007], expertise and competences[Skjerve+2002] and information interfaces [Kiewiet+2005][Kiewiet+2005].

1.1.4 Synthesis

French : Un état de l’art sommaire sur différents domaines comme l’aviation, la santé, le transport férroviaire montre que de nombreux travaux de recherche et enquêtes d’investigation tentent de décrypter la succession d’événements qui ont conduit à un accident pour comprendre comment et pourquoi les accidents sont survenus. Ces travaux visent à enrichir les connaissances pour améliorer la gestion des risques mais aussi à amener les hommes à capitaliser l'expérience et corriger dans le futur leurs erreurs qu'il s'agisse de défauts d'organisation, de défaut de commnication ou encore de mauvaise prise de décision.

English: The last short basic review on different fields as aviation, healthcare or railway safety shows that many investigations and research focused on risks to understand how and why accident happen and to help to prevent and manage risks connected to human errors which are unavoidable. Some of them aims point out particularly communication defaults, organization defaults or wrong decision making. In all these examples, a team has to achieve a global task in a complex environment which is composed of people who must work together in a limited space and time. The next section presents the similarities between all these situations.

1.2 Complex socio-technical system and dynamic situation

In such a complex system as the operating room, the flight deck or the railway cockpit, 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 equipments embed software and sensors which give and control dynamic pieces of information to inform the professionals on the situation. Most of the time, a socio-technical system combine human-human and human-computer interactions with interfaces and monitoring systems.

A socio-technical system [Trist1981][Susman+1986] is more or less complex and this complexity can come from different sources:

- different disciplines, expertise and cultures coexist within the team,
- the operators deal with unanticipated events,
- the operator's interactions are non linear and often unpredictable,
- humans interact with each others and with technical objects or computer systems which deliver technical information,
- the state of the system changes and evolves over the time.

Each individual has both individual technical tasks and collaborative tasks. Every one knows their job and tasks to accomplish to fulfill their role and helps the team reach an identified common goal. For example, in the operating room, 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.

On the other hand, the time is another characteristic which also brings complexity to the situation. As well as the time passes, states of pieces of information change and each operator needs to update their representation of the situation. They try to build the most probable representation of the world, working out the information collected on the changing environment.

Many cognitive models try to understand the human cognition in dynamic and complex situation. Most of them are based on Rasmussen taxonomy named: "Skills-Rules-Knowledge" [Rasmussen1983]. In this model, the activity is separated in automatism, rules and knowledge. Hoc et Amalberti complete this model [Hoc+2007] to take in account the fact that the operator does not react immediately when an information is coming. In fact, the operator uses time to evaluate the dynamism of the situation and anticipate some predictable events.

The heart of this theory is that the operator updates successively their representation of the current situation. Their representation depends on the information received from the environment but also on the operator's knowledge (procedural knowledges or global knowledges).

As human interactions or human-computer interactions can produce hazards, paradoxes can appear and accidents, incidents or adverse events are hardly predictable. To decrease workload and assist professionals in such a complex and dynamic situation, high-level technological equipments track information in real-time as arterial pressure, heart rate in the patient's case, altitude, location. . . for the aircraft Monitoring equipments allow the operators to be informed about the evolution of the situation in real-time and trigger alerts if abnormal values statement are picked up.

But the added benefits also bring unexpected side effects that could compromise safety. Researchers have identified that when automation changes the way human operators perform the tasks, complacency begins to manifest itself, especially in multi-task environments. Even if automation and monitoring equipments assist operators in their complex tasks, they do not replace the humans abilities as communication, decision making, situation awareness that combine essential non-technical skills to manage in a best way a socio-technical and dynamic complex situation.

The two next subsections detail the complex socio-technical systems in two different fields as the operating room in the healthcare area and the flight desk in the aviation area.

1.2.1 The complex healthcare system

In the healthcare context, Vicente [Vicente1999] lists several contributing factors to teamwork system complexity. Effken [Effken2002] 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 [Plasters+2003].

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 [Carayon2006], Plesk and Greenhald [Plsek+2001] and Effken [Effken2002].

The case of the operating room is specific. 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: 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 successively join the operating nurse to accomplish another task... Different groups inside the team are temporary composed to attempt an micro-objective and each one exists for a very short time, namely until the goal is achieved.

1.2.2 The complex aviation system

Another example concerns the aircraft system. Pilots, cabin crews, air maintenance staff... work together in the same space and time. They must react in a best way facing to unpredictable events that could move to a tragic situation. They also collaborate with the air traffic control staff and with the maintenance aircraft staff... They need to use different aircraft commands, configure the aircraft parameters, gather dynamic information about weather conditions and the aircraft location, define flight plan.... Globally, in an aircraft, two people manage mainly the situation : the Pilot Flying and the Pilot Not Flying. The Pilot Non Flying or Pilot Monitoring is the one who has responsibility for monitoring the actions and awareness of aircraft control. Both, they have to collaborate with each other. As the operating room system, the aircraft is a socio-technical system where humans work together and automatic component embedded high-level technology assist them with their tasks.

1.2.3 Synthesis

French Les systèmes dans lesquels les accidents sont les plus probables sont les systèmes socio-techniques complexes dans lesquels la situation évolue de manière dynamique et cette évolution peut modifier les trajectoires qui permettent de réaliser l'objectif commun. Dans ces systèmes, des opérateurs à compétences complémentaires sont réunis dans le temps pour réaliser une tâche commune et globale. Atteindre un objectif commun pour le groupe signifie collaborer mais aussi réaliser des tâches individuelles et techniques en utilisant du matériel de monitoring à haute technicité par exemple. Le bloc opératoire ou encore le poste de pilotage d'un avion sont des exemples de systèmes socio-techniques complexes et dynamiques.

English Globally, the socio-technical complex and dynamic systems are systems in which incidents are hardly predictable because many operators are involved, many events can occur and the situation changes over the time. The chain of events are likely to deeply modify the outcomes and particularly the trajectories that could lead to reach the main team's objective. In such a system, operators who has complementary skills need to get together to accomplish a common mission. Reach a common goal for a team means that each one need to cooperate and work together but also they have to realize some individual and technical tasks using or not high-level monitoring equipment. The operating room or the flight deck of the aircraft are some examples of socio-technical complex and dynamic systems.

1.3 Rules and recommendations: a top-down approach

Many politicians, directors, safety managers are involved by means of laws in the development and the publication of recommendations, rules and procedures that are supposed to help professionals to decrease accidents and increase their performance. On one side, through the legal system, the society places the safety as a priority and on the other side, workers and organizations are reluctant to change their practices. The paradox is that people adore the novelty and innovation but hate the changes.

New equipments, high-level simulators, high-level automation, new safer processes and technologies are supposed to encourage workers to avoid accidental side effects and increase their performance. But, some of them often interpret new rules and procedures as a stronger control of their activities.

Some authors[Carthey+2011] consider the causes of non compliance from organization and professionals as a problem due to an information overload, a multitude of rules, the rules themselves, their complexity and their lack of relevance. They have to deal with local, professional associations or consortium, governmental and international guidelines and policies. Some other authors consider that the humans adapt their behavior facing the policies and the rules thanks to the diversity of situation ever experimented. Hollnagel, Woods and Leveson [Hollnagel+2012] illustrated the ideas that operators adapt the laws and principles when they live in unstable or surprising environments. These deviations from the rules highlight the human ability and flexibility facing to the dynamic and complex situations that are naturally unsettled and unpredictable. The question of education and training is crucial to make workers understand the means of the rules and procedures in the context of risk management.

1.3.1 Aeronautics

Created after the second civil war in 1944, the International Civil Aviation Organization (ICAO) is the specialized agency of UNO gathers 191 states and a large number of global aviation organizations. They develop and publish international Standards And Recommended Practices (SARP) and Procedures for Air Navigation Services. They form the basis of national regulations with a legal status. To avoid accidents, the ICAO implements policies and rules whose some security and safety checklists have been edited. For example, the flight deck checklist aims to ensure that the crew correctly configures the aircraft for the flight. It forms the basis of procedural standardization in the cockpit and allow a cross-checking among the crew members. Locally, in many countries, an office is in charge of Safety Investigations to prevent incidents and accidents. In France, the "‘Bureau Enquêtes et d’Analyses"’(BEA) attached to the Minister of Transport, investigates, analyzes information, develop conclusions determining causes and/or contributing factors of incidents in civil aviation area. In Europe, the European Aviation Safety Agency (EASA) was created in 2002 by the European Commission. It tooks over the functions of the Joint Aviation Authorities of the EU countries. The responsibilities of EASA include drafting of aviation safety legislation and providing technical advice to the European Commission and to the EU Member States, airworthiness and type certification of aircraft and aircraft parts for aircraft operating in the EU, approval of aircraft design organizations world-wide and of production and maintenance organizations inside and outside of the EU.

1.3.2 Marine accidents, shipwrecks example

One of the most famous and tragic accident is the Titanic sinking. From the analysis of this tragedy, expert’s investigation revealed many dysfunctions.

The official US and British inquiries into the sinking of the Titanic recommended some safety practices which are already used nowadays. They published a final report in 30 July of 1912 and the Titanic disaster led to the convening of the first International Convention for the Safety of Life at Sea (SOLAS) on November 1913. For example, International Ice Patrol, S.o.S and number of lifeboats rules have been created based on the British Inquiries recommendations. Yet nowadays, the International Ice Patrol monitors and reports on the location of North Atlantic Ocean icebergs that could pose a threat to transatlantic sea traffic. Since this disaster, the firing of red rockets from a ship must be interpreted as a sign of the need for help. The distress rockets are still used on boats today. There were too few lifeboats available and they had not been properly filled or manned with trained seamen because number of lifeboats depended on the tonnage of the ship. Since the Titanic disaster, lifeboat and raft accommodations are based on the number of passengers for cruises and not merely on tonnage. Titanic museum in Belfast where Titanic was built by Harland and Wolff’s company presents the history of Titanic, the disaster, the inquiries, the recommendations and the actual research on the Titanic (see figure 1.3).

For example, when the disaster occurred, the radio communications were not supplied with a secondary power and did not operate 24 hours along. As the consequence, the rescue services did not hear on time the emergency calls send by the Titanic. The inquiries resulted that

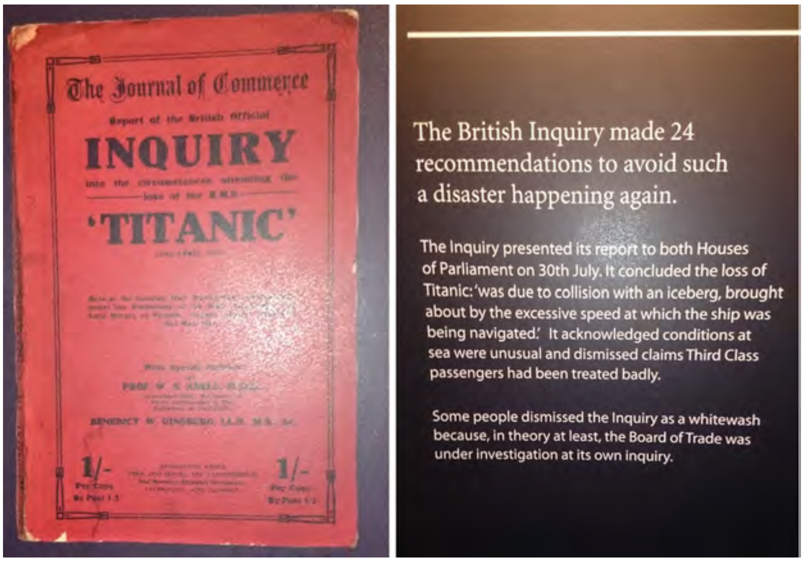


Figure 1.3 – British Inquiry recommendation after the Titanic Disaster (From the Titanic Museum in Befast - Ireland)

the radio communications would be operated 24 hours along with a secondary power supply on passenger ships. This measure would help not to miss distress calls and also to maintain contact with vessels in the same area as well as coastal onshore radio stations.

1.3.3 Heathcare example

In healthcare domain, the World Healthcare Organization (WHO) publishes many recommendations and procedures for patient safety as the checklists [Patient Safety2009] and edits many reports for medical staff over the world on disease preventions as Tuberculosis, Malaria, food safety, aids... The French national healthcare agency 'Haute Autorité de Santé' publish guidelines to improve risks management[Harousseau2012] and adjust the WHO recommendation and checklist to the local French healthcare system. This particular safety surgical checklist is detailed in the section 3.2.

1.3.4 Synthesis

French L'analyse des accidents les plus critiques a conduit les politiques et décideurs à établir de nouvelles règles, recommandations, procédures de sécurité de manière à prévenir ou éviter de nouvelles catastrophes similaires. Du côté des mises en œuvre, les professionnels sont surchargés d'un empilement de règles, recommandations et procédures à suivre qu'ils perçoivent comme des contraintes administratives sans en comprendre totalement leur intérêt. D'autres les considèrent comme un nouveau moyen de contrôler leur activité professionnelle. Par conséquent, les règles et recommandations mal comprises ou mal perçues peuvent être mal appliquées. Selon leur niveau d'expérience ou encore le niveau de perception de leur utilité, ces recommandations de sécurité sont parfois adaptées avec plus ou moins de pertinence dans les organisations et par les professionnels à qui elles sont destinées. La formation des professionnels et des organisations devient essentielle pour qu'ils saisissent leur interêt à mettre en oeuvre les recommandations de sécurité produites après l'analyse de réels accidents évitables qui ne sont malheureusement pas des cas isolés.

English One one hand, the investigations against the most tragic disasters lead most of the time politicians and managers to establish new rules, policies or recommendations to prevent new similar accidents. On the other hand, some professionals often interpret new rules and procedures as a stronger control of their activities. Others consider that the rules, policies or recommendations as a problem due to the stacking of rules, the rules themselves. By the consequence, some professionals an organization refuse to comply and are reluctant to change and apply new rules, recommendations and policies. They adjust or apply safety recommendations according to the level of relevance they consider and the interest they pay attention for. In conclusion, workers and organizations have to be educated to really understand the interest and the relevance of the safety recommendation made from real cases of accident.

1.4 To an educational issue

Education and training is given out for many years by simulating professional work to prevent accident or serious event and it is definitely not an innovation. The Chinese philosopher Confucius said "I hear and I forget, I see and I remember, I do and I understand". Kolb [Kolb1984], Specht and Sandlin[Specht+1991] believe that learning is a process which is constantly modified by experience. "Experiential learning focuses on 'doing' in addition to the 'hearing' and 'seeing' that occur in traditional lecture class" [Specht+1991]. They also argue that experiential learning is a structured activity in which material and principles that are encountered are integrated and applied to new situations.

1.4.1 Simulation

Here the word simulation does not mean a tool to assist in decision-making but the word simulation refers to (1) a digital model which replicates characteristics of a system (2) the ability to lead experimentation, modify the data input that may influence the data output.

So, a simulator could be defined as a software providing a numerical model which replicates a system and proposes representations of its evolution and its behavior by executing it and interacting with. An example based on a mathematical and precisely on a statistical method used to mimic a probabilistic process within computer simulation is the Monte Carlo method. A simulation utilizes sequences of random or predefined numbers as data and provides approximate solutions to a mathematical problems by performing statistical sampling experiments on a computer. Pedgen et al [Pegden+1995] define the simulation as a "process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behavior of the system and/or evaluating various strategies for the operation of the system.'"

Many researches [Kinkade+1972][Pegden+1995][Hays+2012][Salas+2009] refer to simulators as training devices. "Simulation, in general, is any artificial or synthetic environment that is created to manage an individual's (or team's) experiences with reality"' [Bell+2008]. Salas et al[Salas+2009] use the term of simulation-based training (SBT) that encompasses a continuum of technology intended for training purposes. As a result, simulation-based training could be represented by any synthetic practice environment that is created in order to impart the competencies (i.e. attitudes, concepts, knowledge, rules, or skills) that will improve a trainee's performance.

In the aviation training history as in the medicine training history, many examples show that simulation is used for many years. The next two examples show how it was used in the last centuries in these two fields.

Example of simulator for medical training

During the 18th century, Madame Du Coudray teaches the art of birthing to women across French countryside[Ramsey+1999]. Part of the training relies on mannequins allowing to re-enact several obstetric handling. It is estimated that during her 25 years education campaign, she has trained over 4,000 midwives and as a consequence the infant mortality has markedly decreased. Over the next centuries, medicine and medical education have largely benefited from the latest technological and technical advances, owing to their unmatched potential for saving lives.

Example of simulator in aviation training

Whereas the first motorized flight succeeded in 1890 with Clement Ader and with the Wright brothers in 1903, one of the first fight simulators in the world was invented in France in the pilot Antoinette school in 1910. The Antoinette aircraft, invented by Léon Levavasseur, was steered by two wheels, one in each pilot's hand. This system was not intuitive and needed training to learn to use it. So, two young military student-pilots invented a simulator based on two half-barrels of Champagne to familiarize future Antoinette pilots with this non-intuitive steering system.

Figure 1.4 – One of the first flight simulators in the world - 1910 - France

Nowadays, simulation largely widespread and many high technology simulators have been designed to be used in a learning context. Some of them mixed tangible objects and software to reproduce situations or environments designed to an educational purpose. Others simply dedicate real places and real professional equipment to a training purpose. Courses may include live human role-playing or virtual role-playing as they may include high technology simulators. On the other hand, 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 1.5. 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. At the furthest right position (see the reference number 4 on the scheme), 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 on the right (see the reference number 3 on the scheme), 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 [Chin+2009; Liarokapis+2009].

The latter case (see the reference number 2 on the scheme) 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.

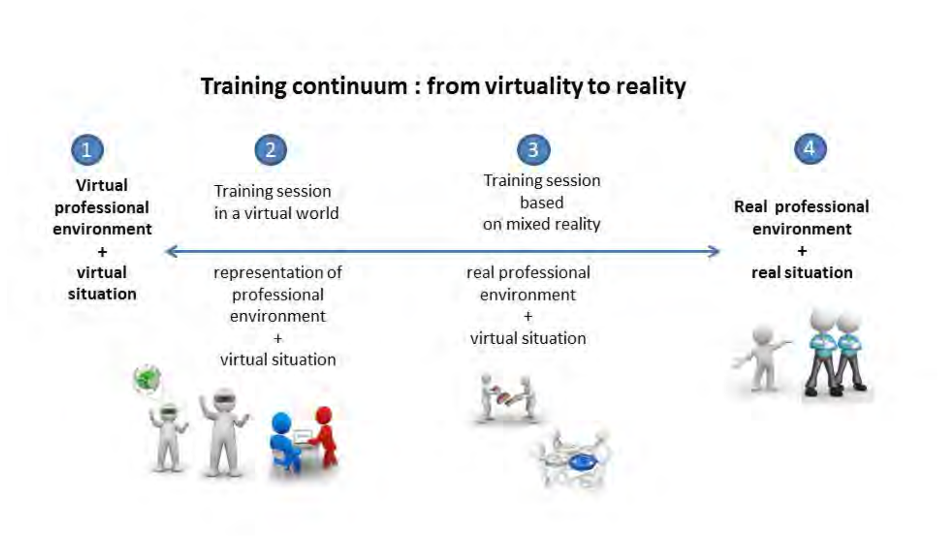


Figure 1.5 – Training continuum: from virtuality to reality

Whatever the training environment and for a long time, education to risk management and safety prevention had considered the individual and technical skills as motor skills having the priority comparing to the other skills. As the consequence, many training programs focus on technical and individual skills to improve operator's performance and slight non-technical skills as teamwork, communication, leadership, decision-making... Nowadays, simulation to train to perform technical tasks which need to train motor abilities or to apply technical procedure is still used because humans are often assisted by machines and equipments which need to be experimented before using them in the real-life professional context.

But, current courses, given out to people whom jobs will be practiced in complex and dynamic situations, expand their modules with educational units entirely dedicated to risk management and safety prevention. These educational units try to take in consideration teamwork and non-technical skills. Most of the time, they include at least one of this three elements: (1) a module which aims to transfer knowledge connected to laws, regulations and theoretical aspects; (2) a module which most of the time takes the form of a storytelling and consists in a description of the chain of events that happened before and during a real-life accident. This chain of events could be analyzed in the classroom. In this module, good practices based on real-life situations could be presented; (3) a module which consists to put teams in a real-life situation. Each student plays a role in an educational environment. In this educational environment, students simulate their professional activities, train to apply safety procedures and train their behavior to ensure safety. After the activity of simulation session, the teacher could highlight failures or non-safety behaviors that could have been identified and should promote safe behavior.

The two next subsections present examples of education training centers in the fields of healthcare and aviation which have used for a long time simulators and simulation.

1.4.2 Simulation in healthcare

In many hospitals worldwide, simulation centers have been created for healthcare education. In most cases, they replicate different medical places as the operating room or the patient's room. They focus mainly on technical skills and aim at reducing the gap between what students learn in textbooks and gestures they are expected to perform in the real professional world. They allow medical and paramedical teams to train to standardized and normal situation and also to specific crisis situations or/and special clinical situations.

The word "simulation", in healthcare training, is used to provide a safe environment for education without any real risk of accident or disease for the patient. Practically, modern simulation in healthcare education corresponds to using an equipment, sometimes a computer software, a mixed reality system "which is a combination of both real and virtual" or a standardized patient for replicating a medical environment and/or a clinic situation and/or a specific pathology. "Simulation is a technique [...] to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner"[Gaba2004]. Simulation in medical education offers many benefits. Firstly, it provides a safe, patient-free environment where mistakes can be experimented repeatedly and without causing any harm. Doing so, simulation also allows addressing rare yet critical situations. Secondly, simulations can easily be tailored to a specific curriculum, selected on demand and arranged by a teacher into a comprehensive collection in order to suit one or several given training objectives. Moreover, as the training does not depend any more exclusively on the practitioner's personal experience, simulators bring a form of standardization which, besides of being a strong asset in favor of equal opportunity, tends to guarantee a good "average level" among the trained practitioners. More advantages of medical simulation are listed by Ziv et al[Ziv+2003].

Although simulation has been resorted to since as early as antiquity, the birth of modern simulation is often dated in the early 1960's[Rosen2008]. A modern simulator is computer-driven, runs an anatomically or physiologically accurate model of a human organ or patient and allows interaction with the medical learners [Murphy+2007]. Modern simulators integrate various degrees of sophistication: from simple multimedia to 3-dimensional virtual reality applications. Those usually provide representations and interactions for task trainers to fully-immersive virtual replicas of the clinical environment and the patient, including audio and touch. Virtual reality has available a large spectrum of techniques and devices in order to produce an illusion of reality with more or less believability. For instance, in the field of anatomic simulators alone, Richard Satava[Satava1996] has highlighted the steady evolution of three generations: anatomical modelling (navigation-enabled immersive representation), physical modeling (featuring interactions, deformations and kinematic constraints) and physiological modelling (where the functions of the organ system are introduced). The contribution of VR to simulators is undeniable [Gallagher+2005] and explains why they are now in common use in medical education for training to many different tasks.

One common use of simulation is for learning therapeutic procedures. This can be achieved using a mannequin, like SimMan (Laerdal) or Human Patient Simulator (HPS, CAE Healthcare), both being physical devices yet embedding extra digital features for simulating a large number of vital functions such as breathing, heart rate, blood pressure and numerous patient sounds. Accessories allow for the replication of more specific diseases (flesh wounds, burn marks, etc). The mannequin can be auscultated, intubated and ventilated; it can undergo a cardiac massage and even endure a defibrillation. Its pulse can be checked in several locations (arm, carotid, femoral artery, etc). A specific location on its arm can even be given an injection or installed a catheter Training to surgical gestures is another context where simulators are used. The Laparoscopic Surgery training simulator (LAP Mentor, Simbionix) is a mobile simulator composed of several instruments dedicated to laparoscopic surgery and a screen displaying the image simulating the endoscope camera. Each instrument, whose handle is the accurate reproduction of a genuine one, can be manipulated with 5 degrees of freedom. The force feedback reproduces the feel of tissue resistance on the surgeon's hands. The simulator embeds several scenarios of increasing difficulty (stitching, gastric bypass, etc.) and sorted in different learning modules (essential, advanced skills, etc) [Websky+2012]. Surgery simulators can grow more complex (and more expensive) like the Endoscopic Sinus Simulator (ES3, Lockheed Martin) for endoscopic sinus surgery. The ES3 aims at providing the most immersive experience by combining high-end graphics, haptic controls, voice recognition, a head-mannequin with realistic anatomy, and a physical replica of an endoscope (see [Fried+2010] for a detailed description). The Vascular Intervention System Training (VIST G5, Mentice) is another example of a large-scale simulator combining physical devices and virtual reality in order to provide the closest possible experience to reality.

The simulators mentioned above are high-fidelity simulators, which means they tend to reproduce the patient or a sub-system with a high degree of realism, both visually and interactively. Yet, high-fidelity is not a prerequisite for efficiency in training [Gallagher+2005] and low-fidelity simulators can be used for teaching processes and conceptual knowledge. This is the case for diagnosis and decision making, which can also be practiced using simulators like virtual patients [Cook+2009]. A virtual patient is often presented as a simple text-and-graphics interactive slide-show where a case study (possibly spanning through several years using ellipses) is presented as a branching scenario where the learner explores the consequences of their decisions. Another illustration of training to non practical skills is the well known Virtual Anesthesia Machine which provides a simplified yet insightful view on the inner operating of an anesthesia machine [Fischler+2008].

1.4.3 Example of aviation training center with simulator

The Federal Aviation Administration proposes lessons learned from Transport Airplane Accidents. The objective is to gather the material with many more of the most historically significant, policy shaping accidents, in order that the lessons that can be learned.

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. The training on flight simulator is intended to maintain the proficiency of flight crews in identifying and reacting appropriately to in-flight emergencies. The Joint Aviation Authorities Training Organization [Joint Aviation Autorities2017] proposes a set of training to improve crew behavior on particular well-known situations.

In 1993, the National Transportation Safety Board identified the misuse of a security checklist as one of the probable causes of 3 major airline accidents in the United States[Degani+1993]. Puentes mentioned the importance to train the pilot's ability skills to control with or without advanced automation the aircraft during the descent[Puentes2011]. One of the most known aviation landing relative to this ability is the successful ditching of the A320 on the Hudson River in 2008. The experimented Captain Sullenberger succeed to manually flight and land the aircraft without any automation.

1.4.4 Synthesis

Résumé : Les formations aux métiers destinés à être exercés dans des situations à risques et complexes s'appuient depuis de nombreuses années sur la simulation comme vecteur d'entrainement pour prévenir les risques liés aux erreurs humaines. Longtemps, ces formations ont priorisé les compétences techniques et motrices à acquérir pour améliorer les performances individuelles et limiter les risques d'erreurs de manipulation et ainsi réduire le nombre d'accidents évitables liés à ce type d'erreurs. Aujourd'hui, les formations aux métiers destinés à être exercés dans des situations socio-techniques complexes s'enrichissent de modules entièrement dediés à la formation à la gestion et prévention des risques. Ces modules de formation essaient de prendre en compte la dimension collective du travail et les compétences non-techniques associées aux risques évitables. Longtemps sous-estimées, ces compétences apparaissent désormais dans les curriculum de formation et commencent à faire l'objet de formation au sein des centres de simulation. Mais reproduire un environnement socio-technique complexe est coûteux parce qu'il necessite la mise à disposition de lieux et de matériels à haute technicité dediés spécifiquement à l'apprentissage. Il parait donc interessant de proposer des environnements virtuels spécifiques dediés à l'apprentissage humain de ce type de compétences.

Summary: For a long time, education to risk management and safety prevention have considered individual and technical skills (as motor skills) having the priority comparing to the other skills. As a consequence, many training programs focus on technical and individual skills to improve operator's performance and slight non-technical skills as teamwork, communication, leadership, decision-making... Nowadays, education courses relative to jobs which will be practiced in complex and dynamic situations expand their courses with courses entirely dedicated to risk management and safety prevention. These courses try to take in consideration teamwork and non-technical skills in situation associated to avoidable risks. For a long time slighted, non-technical skills appear now in the educational curriculum and courses begin to be designed to be taught in simulation centers or training programs. But reproducing a socio-technical and complex environment could be really expensive because specific places and equipment need to be dedicated for training. As a result, it seems to be interesting to develop virtual environment dedicated to training these specific human skills.

1.5 Synthesis

1.5.1 Synthèse en français

De nombreux accidents, dans les transports, l'industrie ou encore dans les parcours de soins résultent d'un enchainement d'événements ponctués d'erreurs humaines et en particulier de défauts d'organisation, de défauts de communication ou de prises de décisions inappropriées.

Quel que soit le domaine, des équipes d'experts tentent d'analyser la chronologie des événements qui ont conduit à un accident et d'en identifier les facteurs contibutifs. Dans les cas les plus critiques, cette analyse conduit à l'élaboration de nouvelles règles et recommandations de sécurité pour éviter de nouveaux drames. Le bloc opératoire dans les établissements de santé ou encore la cabine de pilotage dans un avion sont des systèmes socio-techniques complexes propices à la survenue d'événements imprévisibles qui peuvent avoir des conséquences tragiques. En effet, ces systèmes dans lesquels évoluent des équipes de professionnels constituées d'experts dans des domaines complémentaires ont à coopérer, collaborer et se coordonner alors même que la situation évolue de manière très dynamique. Ces systèmes mettent en jeu des hommes, des matériels et des équipements à haute technicité destinés à faciliter le travail des professionnels en leur permettant de suivre l'évolution des informations au fil du temps.

Les chercheurs et experts au travers de méthodes d'analyse systèmique prennant en compte les facteurs humains centrent leurs travaux sur les compétences non-techniques comme la communication, la prise de décision, la conscience de la situation qui comptent parmi les facteurs humains contributifs d'événements indésirables pouvant survenir dans ces systèmes complexes. Ces travaux amènent les gouvernements et organisations internationales à produire des règles, des législations et recommendations censées améliorer les pratiques pour une meilleure sécurité des biens et des personnes. Mais ces règles et procédures sont souvent perçues comme de nouvelles contraintes administratives qui viennent s'ajouter à la complexité de l'activité professionnelle elle-même. Pour inciter les professionnels à capitaliser leur expérience et à se former à la gestion des risques, de nouvelles législations viennent encadrer leur activité. La tenue de réunions-morbi-mortalité, les comités de retour d'expérience, le développement professionnel continu pour les professionnels médicaux ou bien certifications de vols pour les pilotes sont autant d'exemples qui visent cet objectif.

Les besoins de formation pour améliorer la sécurité, la prévention et la gestion des risques sont immenses. Ils se basent la plupart du temps sur la transmission de savoirs par la capitalisation d'expériences vécues ou bien la formation aux méthodes d'analyse systèmique qui facilitent a posteriori les investigations pour déterminer les causes et repérer les axes d'amélioration. La transmission des savoirs par compagnonnage et capitalisation de l'expérience sont des leviers essentiels. Cependant, la reproduction d'un contexte multi-usagers spatio-temporel complexe propice à l'apparition d'un événement indésirable connue reste très difficile à mettre en oeuvre dans le cadre de formation. Il parait donc interessant de proposer des environnements virtuels spécifiques dédiés à l'apprentissage humain de ce type de compétences.

1.5.2 Synthesis in English

Over the past century, there has been a dramatic increase of industrial accidents such as aviation industry, chemistry, nuclear, health care... Many of them result from successive unpredictable events that include organization defaults, communication defaults or non suitable decisions.

The operating room or the aircraft cockpit are places where unpredictable events can lead to tragedy for the patient or passengers because these systems (named socio-technical systems) combine human-human and human-computer interactions with interfaces and monitoring systems. In these systems, professionals from different fields involved in a team aim to attempt a common goal. At the same time, the situation is dynamic and can rapidly move into an increasingly uncontrollable and dangerous situation. To help teams involved in a dynamic situation, humans have developed innovative technologies and equipments. Such equipments are welcome but they are unsatisfactory to avoid communication defaults or wrong decisions.

Whatever the domains, teams of experts try to analyze the chronology of the events before an accident. They investigate to identify errors, failures and contributive factors that have leaded to the accident. Most studies in the field of risk management have only focused their research on non technical skills such as communication, collaboration, decision making or situation awareness. In the most critical cases, experts and politicians propose new rules and recommendations basing their work on the results of expert's analysis. Doing this, they intend to avoid new disaster and tragedy.

The point is that professionals receive these new safety recommendations as new regulatory constraints. They do not understand their interest but the complexity they add to their job. To foster their training on professional tasks, new rules intend to help them to accumulate experience and disseminate knowledge. This is the case for aircraft pilots and health care professionals.

However, many experts stressed the training needs in terms of simulation to improve risk management, few programs propose training on risk management. Most of them focus on technical skills, storytelling of real adverse events or learning techniques of analysis that make easy to understand what happened and what should have been done. Disseminating knowledge and sharing experience is essential to improve risk management learning. However, very few programs try to propose team training simulation. The fact is reproducing a socio-technical learning context is complex.

The present research focuses on the way to train people in a collaborative virtual environment to avoid communication defaults which can increase the risk of crash. It implies to have a look at the results of risk management, human factors, social and psychology science to consider the communication, the decision-making process, the situation awareness concept all gathered in the frame of socio-technical and dynamic complex system. Involving teams to investigate inter-professional collaboration in a virtual environment should enable them to experiment situations built with risky conditions. It should allow them identify errors, fix them and try to evaluate miscellaneous causes of near-miss. The present work focuses on designing a collaborative digital learning environment to help providers to improve performance of teams involved in complex system in which causes of serious events are underlying to a lack of communication.

Chapter

2

Goals and challenge

2.1 French version

De nombreux rapports sur la gestion des risques et la simulation dans des contextes socio-techniques mentionnent l'importance de créer des environnements et des programmes de formation reproduisant avec fidelité l'environnement professionnel pour que les équipes de futurs professionnels puissent s'exercer [Riem+2012] [Gough+2012] [Crichton+2004] [Reese+2010] [Cornes2015] [Granry+2012] [Halverson+2011]. Globalement, les experts s'accordent sur la nécessité et l'intérêt de former les équipes interprofessionnelles mais la question de l'évaluation des compétences à aquérir et le moyen de les évaluer restent encore flous [Gordon+2005] [Rogers+2017]. Pour autant, les compétences non techniques apparaissent dans les curricula de formation des pilotes pour l'aviation dès 2002 [Authority2002].

L'entrainement au travail en équipe interprofessionnelle par la simulation est non seulement coûteux mais également très complexe. Plusieurs éléments permettent de mieux comprendre la complexité de mise en oeuvre d'une telle formation. Un certain nombre d'entre eux sont listés ci-dessous :

1. Recréer les conditions du travail d'équipe est coûteux pour une formation dans un lieu physique réel : matériels, équipements...

2. La question de la formation en équipe reste complexe. Elle nécessite de disposer d'outils et de méthodes avancées permettant un contrôle total et permanent de la situation pédagogique autant lors de sa mise en place en début de séance qu'au cours de l'entraînement [Donaldson2009]. Une autre difficulté concerne le contrôle de l'activité de chacun des membres de l'équipe [Salas+2001] [Reese+2010].

3. La question du contrôle par le formateur du contenu de la séance est cruciale. Ce contrôle est nécessaire afin que le travail d'équipe puisse se dérouler selon les objectifs préalablement visés par le formateur [Alinier+2008]. En effet, ce contexte de formation impose de ne pas dévoiler les risques encourus pour ne pas orienter le comportement de

l'équipe en formation ce qui implique aussi une inconnue sur la gestion de la situation par l'équipe en formation. La priorisation des tâches ou des sujets par l'équipe qui gère la situation peuvent ne pas correspondre à ce qu'avait imaginé l'expert. Par conséquent, les écarts à la normale et les objectifs visés par le formateur peuvent être totalement ignorés, non-identifiés ou bien perçus comme secondaires par l'équipe en charge de gérer la situation.

4. Recréer les conditions d'apparition d'un incident mettant en jeu plusieurs acteurs est extrêmement difficile et même impossible dans le cas de formation pluridisciplinaire qui aurait lieu dans un environnement physique identique à l'environnement professionnel.

5. Débriefer une séance de formation basée sur une simulation en équipe est extrêmement compliqué [Fanning+2007]. En effet, le formateur ne peut pas visualiser l'ensemble de l'activité de tous les acteurs de l'équipe en temps réel et par conséquent le débriefing ne va pouvoir porter que sur la perception qu'il a eu de l'activité de certains operateurs. Alors, il est très difficile d'identifier les écarts ou erreurs commises au cours de l'activité qui ont pu générer une situation plus critique encore. L'évaluation est d'autant plus difficile que les compétences mises en jeu par les professionnels dans ces situations à risque ne sont pas seulement techniques et individuelles. Mais ces compétences mettent en jeu des compétences relatives à la communication, la prise de décision, l'organisation et la planification des tâches... et sont quasiment impossibles à évaluer lors d'une formation dans un lieu physique car personne en réalité n'exprime le cheminement de son raisonnement. Par conséquent, il est très difficile de considérer le raisonnement de l'équipe dans son ensemble et d'en identifier les erreurs de logique, de raisonnement ou d'interprétation. Dans tous les cas, le formateur doit avoir à la fois des compétences techniques, des compétences d'enseignement mais aussi une bonne psychologie pour mettre en confiance l'équipe [Rall+2000]. Par exemple, les situations et objectifs pédagogiques ne doivent être dévoilées intégralement pour ne pas orienter les comportements[Dieckmann+2009]. S'ajoute à cette difficulté, celles liées à la composition inter-professionnelle de l'équipe qui impose au formateur d'avoir des connaissances pluridisciplinaires [Salas+2011].

Les environnements numériques virtuels offrent de nombreux avantages en terme de coûts et de risque. Ils n'engendrent pas de besoins particuliers en terme de lieux et d'équipements. Ils permettent de récréer virtuellement l'environnement de travail en équipe [Cobb+2008].

Les professionnels peuvent être représentés par des humains virtuels et peuvent être pilotés soit par une intelligence artificielle soit par de vrais humains. Ils évoluent ainsi dans un environnement virtuel dans lequel sont agencés les objets, matériels et équipements utiles à la réalisation de tâches professionnelles. La réalité virtuelle et les serious games apportent de nouveaux atouts en ce qui concerne le travail en équipe, la collaboration, la communication entre collaborateurs virtuels.

Objectif :
Un des principaux objectifs de ces travaux portent sur l'entrainement des équipes à la gestion des risques liés à des defauts de comunication dans un environnement socio-technique complexe.

Dans cette thèse, le travail portera sur la mise en place d'un environnement virtuel, interactif, multijoueurs, temps réel permettant aux équipes de s'exercer à gérer des situations professionnelles standards ou à risque liés à des défauts de communication et/ou de prise de décision.

Nous nous attacherons à créer des modèles utiles pour reproduire l'activité individuelle et collective au sein d'une équipe, l'évolution dynamique du contexte, la collecte d'information, les échanges d'informations, les discussions synchrones amenenant à une prise de décision. Il s'agira aussi de fournir des modèles utiles au contrôle de la situation pédagogique, au suivi et l'analyse par le formateur de l'activité in situ mais aussi a posteriori.

Pour illustrer ce travail, nous nous placerons dans le contexte socio-technique du bloc opératoire. Afin d'évaluer les concepts et d'obtenir des résultats scientifiques, deux scénarios mettant en oeuvre le système de communication, le système de prise de décision et le modèle d'objectifs ont été implementés :

1. un scenario basée sur une situation 'standard' dont les conditions initiales sont idéales ie : aucune erreur n'a été commise avant ou bien elles ont toutes été detectées et corrigées avant que l'équipe se voit confier la mission. Ce scénario met en oeuvre 2 personnages ayant à disposition chacun une cinquantaine d'actions et 5 décisions collaboratives sont disponibles au cours de la partie. Environ 500 objectifs permettent de décrire les situations finales attendues. Ils permettent à l'issu d'une partie l'affichage de messages de débriefing à l'équipe.

2. un scénario 'à risque' mettant en oeuvre les conditions initiales d'apparition d'un événement indésirable grave. Ce scénario a été conçu de manière à rendre probable 4 types d'événements indésirables graves : erreur d'identité du patient, erreur de site opératoire, risque infectieux et crise d'anxiété aigüe du patient. Il met en oeuvre 3 personnages ayant à disposition une centaine d'actions, 5 décisions collaboratives et environ 500 objectifs permettant l'affichage de messages de débriefing à l'issu d'une partie.

2.2 English version

One of the critical components of a comprehensive strategy to improve the safety of a patient as well as passengers of a flight is to create education and training environments that support healthcare providers to train professionals and future professionals to identify errors, evaluate causes and take appropriate actions to improve their team performance. Many reports and experts point the importance to design educational environment and educational programs to reproduce with high fidelity the professional environment [Riem+2012] [Gough+2012] [Crichton+2004] [Reese+2010] [Cornes2015] [Granry+2012][Halverson+2011].

Globally, there is growing agreement regarding what should be assessed, which relates to students developing inter-professional skills (both skills technical or non-technical). However, the point relating to how the students' skills should and could be assessed is less clear [Gordon+2005] [Rogers+2017]. In aviation, the non-technical skills appeared in the flight crew training in 2002 [Authority2002].

Experts stress that training future professionals and professionals on real-life based events should be a good way to increase their performance if they encounter the same kind of situation. Involving the teams to investigate inter-professional collaboration in a virtual environment should enable them to experiment risky conditions, to identify errors, adapt their behavior, make suitable decision and then evaluate miscellaneous causes of near-miss.

Whether in aerospace, healthcare or nuclear safety, professionals and experts carry out inspections to investigate serious complaints, serious accidents and near-misses, incidents and occurrences of non-compliance. Most often, among the root-causes 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 [Kolb1984]. Specht and Sandlin [Specht+1991]believe that "experiential learning focuses on 'doing' in addition to the 'hearing' and 'seeing' that occur in traditional lecture class". They also argue that experiential learning is a structured activity in which material and principles that are encountered are integrated and applied to new situations. So, using a Digital Collaborative Virtual Environments for Training (DCVET) to train people on near-misses or critical situations should allow to present teamwork situations where operators can both act and communicate as in a real-life 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.

However, many constraints and difficulties restrict the development of inter-professional training and education. Some of them are mentioned below:

1. recreating the conditions of inter-profesionnal work for training is extremely expensive. It implies duplicate equipment, rooms, places, materials...
2. The point relating to the team training remain complex. It imposes to entirely control the educational context by means equipment, methods and advanced tools [Salas+2001] [Reese+2010] [Donaldson2009]. The trainer needs to entirely manage both the teamwork activity as a whole and the individual activity related to each team member.
3. The point relating to the control of the educational context is extremely complex. It implies both to control the educational content and educational objectives from the beginning to the end of the team training session [Alinier+2008]. Several reasons can explain it: (1) there is a large uncertainty relating to the team behavior (2) the team context offers immense possibilities to the team to manage the educational situation they must deal with. This uncertainty related to the team behavior may lead to a situation that can not be anticipated by the trainer. As a consequence, the initial educational objectives may be ignored, non identified or felt like non-priority goals.
4. Recreating artificially the conditions that lead the team to an accident is extremely difficult. Near Impossible is the task in a training context that takes place in a real physical room.
5. The point relating to the analyze during the training session and its assessment is complex too. The trainer must pay attention to each member of the team, understand what's going on, imagine what is the logic of reasoning, analyze and memorize mistakes...
6. The point relating to the debriefing at the end of a training session is also complex [Fanning+2007]. It implies that the trainer identified all the mistakes or the deviations from the expected behaviors or the security procedures. As the team's activity influences the progress of the educational situation, the trainer must identify clearly what happened to explain the state of a possible critical situation at the end of a session. However, the trainer as a human is not able to analyze in real-time, memorize and predict

> neither each individual behavior nor team behavior. Furthermore, the task is much more difficult as the skills to assess are both individual, collaborative, technical and non-technical. Among the skills the team work on, there are communication, decision-making, scheduling, leadership. . . The trainer's task is much more difficult as they can not imagine what is the reasoning that leads someone to do something. More globally, it is near impossible to identify reasoning faults or logical errors. Furthermore, the trainers must have sufficient technical skills relating to all the jobs that are represented in the inter-professional team [Salas+2011]. They need to gather educational skills as teacher, technical skills as professional and good interpersonal skills to win the trust of student's team [Rall+2000]. For example, the trainer must not reveal the real educational objectives specially for a risk management training in order not to have an influence on their student's behavior [Dieckmann+2009].

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 report, 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.

In the next sections, the topic will be restricted to the operating room context in the healthcare field to demonstrate on an example all designed features.

Chapter

3

Case of study : the operating room

3.1 The teamwork in the operating room

In an operating room located in an industrialized country, there are at least 5 professionals: the surgeon, the anesthetist, the operating nurse, the anesthetist nurse and the moving nurse. Many drugs, medicine, surgical or anesthesia instruments are stored into closet or dessert trolleys.

The composition of the "operating team" is heterogeneous. The "operating team" comprise the surgeons, anesthesia professionals, nurses, technicians and other operating room personnel involved in surgery, each of whom plays a role in ensuring the safety and success of an operation.

The operating room represents the highest risk for the patient, as 65% of adverse events in healthcare are related to surgery[Zegers+2011]. It is a complex environment[Effken2002]:

1. different disciplines, expertise and cultures coexist within the team
2. the operators cooperate for patient care and 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 computerized systems which deliver technical information,
5. the state of the system changes and evolves over time.

A dozen of dimensions of complexity in health care are described by Carayon[Carayon2006], Plesk and Greenhald[Plsek+2001] and Effken[Effken2002]. Each team member has their

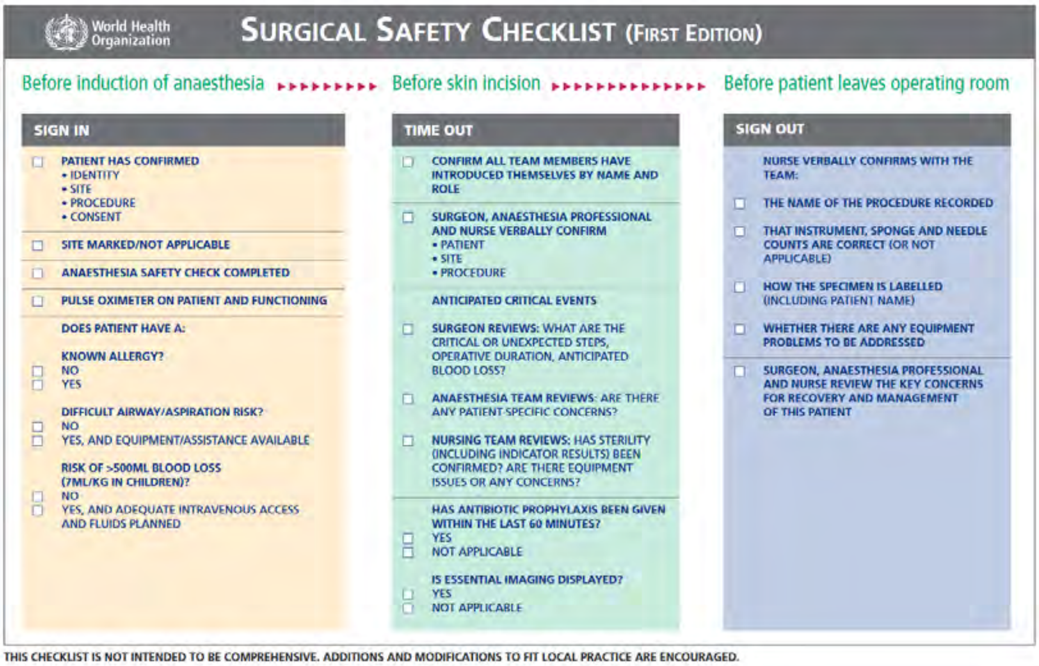
Figure 3.1 – The operating room

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 [Plasters+2003] to understand what is going on. Many reports note that communication default is most of the time listed as one of the root causes or contributing factors of an adverse event [Halverson+2011; Joint Commission2008; Kohn+2000; Lingard+2004; Pennsylvania Patient Safety Authority2007]. Wrong surgery site (WSS), wrong patient events or wrong procedure are often reported[Authority2012; Seiden+2006] although they appear in 1.7 to 3.6 events out of 100,000 operations[Seiden+2006]. More recent studies shows how errors result from misinformation (e.g., incorrect information obtained from other departments) and misperception (e.g. from right-left confusion when interpreting imaging results[Hempel+2013]).

The median prevalence estimate for wrong site surgery was 0.09 events per 10,000 surgical procedures [Hempel+2013]. In healthcare, 54 percent of surgical adverse events occurring in industrialized countries are considered as avoidable.

3.2 The WHO surgical safety checklist

In 2009, the World Alliance of Patient Safety project, launched in 2004 by the World Health Organization (WHO), published a list of recommendations and security checklists to prevent adverse events in operating theaters during surgical procedures[Patient Safety2009]. The WHO checklist (see fig. 3.2) displays 3 columns that identifies the three specific time period of a surgery: (i) from the patient's arrival to the induction of anesthesia, (ii) from patient's induction to skin incision and (iii) from skin incision until the end of the operation. Each corresponds to a specific period in the normal flow of work: Before the induction of anesthesia ("sign in"), before the incision of the skin ("time out") and before the patient leaves the operating room ("sign out"). In each phase, a checklist coordinator must confirm that the surgery team has completed the listed tasks before it proceeds with the operation.



World Health Organization

SURGICAL SAFETY CHECKLIST (FIRST EDITION)

Before induction of anaesthesia ▸▸▸▸▸▸▸▸▸ Before skin incision ▸▸▸▸▸▸▸▸▸▸▸▸▸▸ Before patient leaves operating room

SIGN IN

- ☐ PATIENT HAS CONFIRMED
  - IDENTITY
  - SITE
  - PROCEDURE
  - CONSENT
- ☐ SITE MARKED/NOT APPLICABLE
- ☐ ANAESTHESIA SAFETY CHECK COMPLETED
- ☐ PULSE OXIMETER ON PATIENT AND FUNCTIONING

DOES PATIENT HAVE A:

KNOWN ALLERGY?
- ☐ NO
- ☐ YES

DIFFICULT AIRWAY/ASPIRATION RISK?
- ☐ NO
- ☐ YES, AND EQUIPMENT/ASSISTANCE AVAILABLE

RISK OF >500ML BLOOD LOSS (7ML/KG IN CHILDREN)?
- ☐ NO
- ☐ YES, AND ADEQUATE INTRAVENOUS ACCESS AND FLUIDS PLANNED

TIME OUT

- ☐ CONFIRM ALL TEAM MEMBERS HAVE INTRODUCED THEMSELVES BY NAME AND ROLE
- ☐ SURGEON, ANAESTHESIA PROFESSIONAL AND NURSE VERBALLY CONFIRM
  - PATIENT
  - SITE
  - PROCEDURE

ANTICIPATED CRITICAL EVENTS
- ☐ SURGEON REVIEWS: WHAT ARE THE CRITICAL OR UNEXPECTED STEPS, OPERATIVE DURATION, ANTICIPATED BLOOD LOSS?
- ☐ ANAESTHESIA TEAM REVIEWS: ARE THERE ANY PATIENT-SPECIFIC CONCERNS?
- ☐ NURSING TEAM REVIEWS: HAS STERILITY (INCLUDING INDICATOR RESULTS) BEEN CONFIRMED? ARE THERE EQUIPMENT ISSUES OR ANY CONCERNS?

HAS ANTIBIOTIC PROPHYLAXIS BEEN GIVEN WITHIN THE LAST 60 MINUTES?
- ☐ YES
- ☐ NOT APPLICABLE

IS ESSENTIAL IMAGING DISPLAYED?
- ☐ YES
- ☐ NOT APPLICABLE

SIGN OUT

NURSE VERBALLY CONFIRMS WITH THE TEAM:
- ☐ THE NAME OF THE PROCEDURE RECORDED
- ☐ THAT INSTRUMENT, SPONGE AND NEEDLE COUNTS ARE CORRECT (OR NOT APPLICABLE)
- ☐ HOW THE SPECIMEN IS LABELLED (INCLUDING PATIENT NAME)
- ☐ WHETHER THERE ARE ANY EQUIPMENT PROBLEMS TO BE ADDRESSED
- ☐ SURGEON, ANAESTHESIA PROFESSIONAL AND NURSE REVIEW THE KEY CONCERNS FOR RECOVERY AND MANAGEMENT OF THIS PATIENT

THIS CHECKLIST IS NOT INTENDED TO BE COMPREHENSIVE. ADDITIONS AND MODIFICATIONS TO FIT LOCAL PRACTICE ARE ENCOURAGED.

Figure 3.2 – The World Health Organization - Surgical Safety Checklist

The ultimate goal of the WHO Surgical Safety Checklist is to help ensure that teams consistently follow a few critical safety steps and thereby minimize the most common and avoidable risks endangering the lives and well-being of surgical patients.

Different practice settings adapt the checklist recommendations to fit to the local practice and to their own circumstances but the WHO surgery checklist is designed to help ensure that surgical teams are able to implement the checklist consistently. By following a few critical steps, health care professionals can minimize the most common and avoidable risks endangering the lives and well-being of surgical patients.

Studying complex systems, Reason[Reason2013] shows that most of the time, accidents result from multiple successive failures which could not have been corrected or stopped in time. The WHO checklist aims to build different barriers to prevent certain types of errors that tend to be committed in each of these three stages[Busemann+2012]. Haynes et al [Haynes+2009] showed that the use of the checklist significantly lowers surgical morbidity and mortality.

The recommendation imposes to identify a coordinator who is responsible to manage the safety procedure and check the boxes on the list. This designated Checklist coordinator will often be a circulating nurse, but it can be any clinician or healthcare professional participating in the operation. In practice, the role of checklist manager can be attributed to anyone. The role of the checklist manager consists in checking information from different sources, on different topics and making cross-control. He/She must be allowed to confirm that the team has completed its tasks before it goes further. As operating teams become familiar with the steps of the Checklist, they can integrate the checks into their familiar work patterns and verbalize their completion of each step without the explicit intervention of the Checklist coordinator. In case of doubt, they can stop the surgery process or ask for help.

Fudickar et al[Fudickar+2012] show the effect of the WHO Surgical Checklist on communication. “The checklist should be understood not merely as a list of items to be checked off, but as an instrument for the improvement of communication, teamwork, and safety culture in the operating room, and it should be implemented accordingly”. Yet, very few specific courses exist to help professionals and students to learn how to use the checklist and improve their teamwork.

3.3 Non-technical skills in the Operating Room

The next paragraph presents the different skills which interfere in a socio-technical system such as the operating room.

In medical education and medical simulation training centers, during many years, traditional courses has slighted cognitive skills as communication, management, cooperation, interviewing, task scheduling. . . But, the required skills and competences set out to manage complex, dynamic and socio-techical situation should include not only technical and motor skills, but non-technical and cognitive skills. The last section highlights that skills as communication, decision making appear at the first places among the human contributive factors of serious adverse events in a socio-technical dynamic and complex system.

Flin et al [Flin+2010] point the importance of non-technical skills that are not directly linked to anaesthetist’s technical expertise. Non-technical skills are divided in two categories : interpersonal skills and cognitive skills (Neyns, 2011). Interpersonal skills as communication, leadership and coordination. . . are skills that make teamwork effective to reach a common goal. Cognitive skills are composed of task management, situation awareness [Endsley1995][Kaber+1998]and decision making. Situation awareness is based on pieces of information that can be seen during the situation. From all the information collected, each one makes their own mental representation according to what they have collected, memorized and understood. Decision making skills consist in assessing the situation, listing the possibilities, identifying their costs and benefits and then decide the most suitable action to do or make a diagnostic on what’s happening (Gaba, 1989). Keyton and Beck [Keyton+2010a][Keyton+2010b] stress the difference between the macro-cognitive framework and the communication framework. “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 co-construct meaning”[Keyton+2010a]. Here, the word “communication” refers to macro-cognition framework. The team members make their decisions based on their own representation of the situation. The lack of communication can lead the team to build a restricted mental and erroneous representation which could breed inadequate decision-making regarding the real living situation. Team situation awareness is one of the critical factors in effective teamwork [Salas+1995] and can impact the success of the final achievement. Mathieu et al [Mathieu+2000] showed the influence of shared mental models on team process and performance. Some researches focus on the risk management in healthcare and highlight the importance to develop habits of action [Norros+1999]. Sharing information could allow the team to build a common and more realistic representation of the situation. Therefore, decisions are likely to be more suitable. The collaborative decision making problems [Sterman1989] can be addressed through argumentation and collaboration between the users involved. On the basis of video clips recorded during real-life surgery operations, Devreux[Devreux+2014] studied how professionals communicate according to the level of experience they have. His research highlights how experts adapt their strategies by collecting the same information from different sources in order to check their coherence.

A recent study by Gleeson et al [Gleeson+2015] involved the importance of a pre-anaesthetic briefing in a multidisciplinary team to ensure that everyone are aware of the situation, the plan and their role. “Situational awareness is vital to ensure that fixation errors are avoided. Disciplined communication and thoughtful followership ensure good team dynamics"[Gleeson+2015]'.

Many analysts now argue that the strategy of training has not been successful. Halverson et al. for example mentioned that "'A program that teaches teamwork and communication skills is one strategy that may improve communication among members of the operating room team."'[Halverson+2011]. A french national report on simulation in healthcare published in 2012 by the “Haute Autorité de Santé” [Granry+2012] presents an international overview on healthcare simulation.

3.4 Synthesis

Synthèse 65% des événements indésirables survenus dans les établissements de santé sont des événements liés à la chirurgie [Zegers+2011] et 54% des événements indésirables dans les pays industrialisés sont considérés comme évitables [Gawande+1999]. Le bloc opératoire est identifié comme un lieu à haut risque pour le patient. En effet, ce système système socio-technique complexe, met en scène des équipes pluridisciplinaires oeuvrant dans un but commun : prodiguer des soins à un patient. Parmi les causes profondes référencées ayant conduit à un événement indésirable en France, 24% sont liées à des défauts de communication. Cette tendance est confirmée au niveau international [Halverson+2011][Kohn+2000][Lingard+2004]. Même si de nombreuses recommandations, procédures de sécurité et réglementations relatives au développement professionnel continu ont été publiées par l'Organisation Mondiale de la Santé (OMS), la Haute Autorité de Santé ou encore le Ministère de la Santé en France, les professionnels perçoivent cela comme de nouvelles contraintes qui viennent s'ajouter à la complexité de leurs métiers. De nombreux rapports pointent l'importance de développer des programmes de formation centrés sur les compétences non-techniques et en particulier le travail en équipe, la collaboration et la communication. Halverson aux Etats-Unis [Halverson+2011] ou encore Granry en France [Granry+2012] soulignent importance de proposer des programmes de formation par le biais de la simulation.

Synthesis The operating room is a high-risk area for the patient. In healthcare, 65% of adverse events in healthcare are related to surgery [Zegers+2011]. 54% of surgical adverse events occurring in industrialized countries are considered as avoidable events [Gawande+1999]. Many studies show that human factors are most often listed among the multiple causes of an accident or a near-miss. They also point that the most current root causes of adverse events in the operating room is due to a communication problem [Halverson+2011][Kohn+2000][Lingard+2004]. The composition of the team is heterogeneous and each team member has their own technical skills and responsibilities. There are multiple interactions that influence the evolution of the system but a successful surgery depends on what information is dynamically exchanged to understand what is going on [Hempel+2013][Plasters+2003]. Experts like Halverson [Halverson+2011] in USA and Granry[Granry+2012] in France stress the training needs in terms of non-technical skills using simulation for example.

Part II

State of the art

Chapter

4

Multiplayer virtual environments for training

4.1 A digital collaborative environment

For many years, researchers try to facilitate collaboration and coordination using large interactive displays. LiveBoard project, for example, focused on supporting collaborative activities through electronic whiteboards [Elrod+1992]. Others design tangible objects to support collaborative work as interactive electronic wall or interactive table [Streitz+1999] [Johanson+2002] [Laborie+2005]. As an illustration, Laborie et al. [Laborie+2005] designed an issue composed of public and semi-public interfaces dispatched in the aeronautical environment to support the collaborative process that facilitate team awareness during the final assembly line of the Airbus A380 aircraft. This system is tangible as it was deployed in the real factory.

Another example is the "andon" system which reported the occurrence of a problem on an industrial assembly line in Toyota industry [Monden2011] and appeared as a repressive system because it pointed out the faulty operator who pulled the alert and stopped the assembly line.

The present research aims to propose a virtual collaborative environment where a team could read documentation, work and exchange ongoing information and a leader could make decision facing to a problem.

Representing a virtual collaborative environment where a team could achieve a global main goal implies that each member of the team could accomplish individual tasks and as a consequence they could contribute to reach the main mission. This section describes the collaborative environment system that should make possible virtual teamwork and individual tasks completion in a VE.

Representing a virtual environment for training implies to represent avatar's in the virtual world. The avatar's representation is even more important in a real-time collaborative virtual world. Capin et al [Capin+1997] 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 chat-bots, to synchronize virtual character's faces or body motion with their speech and combine interaction with specific animations and rendering[Egges+2007; Kopp+2004; Ma+2004].

All these components contribute to a better understanding on what is going on in the collaborative virtual scene, but this thesis does not focus on these topics. The virtual environment we work on would represent avatars and provide signs and feedback based on the characteristics expressed by Capin et al.

4.1.1 Interactive objects, tasks and behaviors

The general model for interaction, adopted in virtual environments and immersive games, is inherited from Gibson's affordances theory [Gibson1978]. This psychological theory has been widely influential to the computer graphics community and brought to many implementations, the most famous being smart objects[Kallmann+2002]. Smart objects are virtual objects whose description includes visual or interactive properties (what do I look like? How should I be interacted with?) but also the behaviors of both the object and the agent interacting with the object once the interaction is triggered. In addition, smart objects broadcast their interaction abilities to the users, so the interactions can be presented and selected graphically inside the virtual environment.

The behavior attached to an object is composed of 4 parts: preconditions that must be true for a behavior to be carried out, the name of the behavior for reference, the visual animation associated to the behavior and the changes resulting from performing the behavior. Several insights into how cyberspaces (or virtual worlds dedicated to host several users) should be designed are given by the creators of the game in [Morningstar+1990]. Particularly, an "object-oriented data representation is essential: the basic objects from which you build the system should correspond more-or-less to the objects in the user's conceptual model of the virtual world, that is, people, places, and artefacts".

Finally, the behavior of an object can be triggered by means of clicking an action label visually attached to this object.

It implies that designers studied the professional activity and know the expected behavior of objects they must reproduce in the virtual world.

4.1.2 Representation of a team activity in a collaborative environment

To foster teamwork in a VE, actors need to identify the others and to understand what task the others are doing. The VE must provide features that help actors to visualize individual's action with animation for example and allow them to do collaborative task.

Clinispace uses a graphical metaphor to help the teammates to know what tasks the others are doing. The chronology of teammates' recent actions is displayed on the GUI using a scrolling text along the crawl from left to right. Each information contains the time when the action was done and the actor who made the action.

Multi-player real-time games like MMORPG and MOBA use tricks and systems to make players collaborate and plan individual actions which compose the teammates's strategy. These systems allow players to synchronize an attack using a common strategy.

Many digital games like Call of Duty, Warcraft, Heroes of Might and Magic : Hammers of fate, Defense of the Ancients, League of Legends. . . use a map to locate the teammates and the enemies. Players can use the map to alert the others and deploy a common strategy with a 'ping system'. This system allows players to click on the map and display graphical symbols on the area. The alert appears graphically on the map for every teammates with a symbol as a shield to indicate a withdrawal for example. The alert can also indicate to the others to deploy a strategy named 'Gang Kill' that consists in gathering fighters to suddenly attack one enemy. With this attack based on elements of surprise, there is no chance to survive against the numerical superiority for who suffers this attack.

If the VE intends to foster collaboration between teammates, the capacity or expertise of individuals should to be compatible. The industrial collaborative work is particularly relevant because it requires a large variety of expertise during the design and manufacturing stages. Gerbaud et al. [Gerbaud2008] propose a model to describe individual and collaborative actions in a training scenario both for humanoids and teammates. They use their models in a collaborative virtual environment for training to teach collaborative procedures.

4.1.3 Global main objective based on non-linear tasks and conflicts in a team

In a collaborative virtual environment that intends to represent a virtual socio-technical context for training, the players need to know and understand what they are supposed to do. The goals must be clear and displayed at the beginning of the training session. All the team members must share the same goal. They must globally know what is the initial situation they have to manage and what they are supposed to do to reach the expected objective.

Non-linear tasks

The main point is that goals in a socio-technical system can be reached using many different ways. At least, three points can be lighten: - a task can be done by one or another operator - a task is composed of sub-tasks that can be done by a sub-group - even if operating procedure exists, the order of the tasks that compose a bigger one can be free.

Training a team in a virtual environment implies to give them impression of freedom as in real-life work. Doing that means that we make them able to prefer to accomplish one task rather than another. This feeling of freedom is a point that leads to complexity and the size of the team increases the number of possible combinations.

Rasmussen picked this problem up mentioning “The problem is that all work situation leave many degrees of freedom to the actors for choice of means and time for actions even when the objectives of work are fullfilled and task instruction or standard operating procedure in terms of sequence of acts cannot be used as a reference of judging behavior” ([Rasmussen1997]

Another element which adds complexity is that some tasks are cooperative. In other words, operators need to be available at the same time to accomplish a cooperative task. Sub-group needs to be constituted for a limited time to accomplish a cooperative task. Depending on the cooperative tasks, sub-groups may not be the same for any tasks.

In conclusion, the complexity of a teamwork situation comes out on a great number of possible combinations for each actor but also for the team.

Intellective task and decison making task

Steiner[Steiner1972] classifies the tasks according to 4 criteria on basis of how members contribution are allowed to be combined to realize the final product/task.

Mc Grath[McGrath1984] establishes a model named ‘circumplex’ concerning the teamwork tasks. His model gathers different theories whose Steiner’s theory is included. 8 categories of task are identified: planning tasks, creativity tasks, intellective tasks, decision-making tasks, cognitive conflict tasks, mixed motive tasks, and performances/psychomotor tasks.

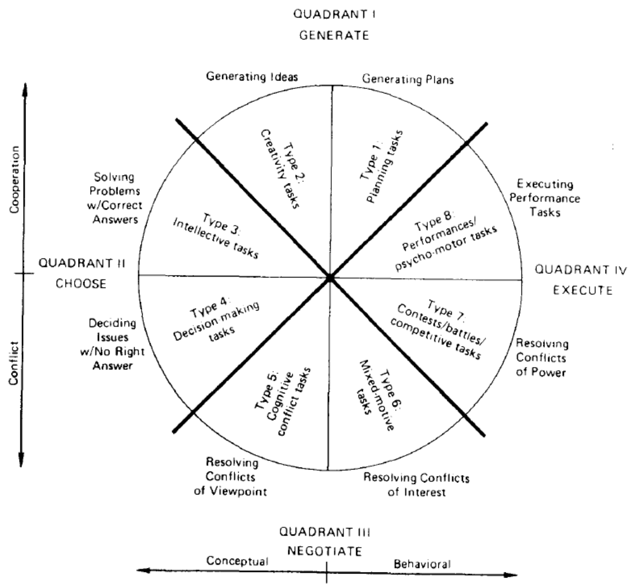


Figure 4.1 – McGrath groups task Circumplex.

McGraph displays a powerful message. In the first quadrant named 'Generate', two categories of task are represented, scheduling and creativity tasks. The second quadrant named 'Choose' is composed of intellective tasks and decision making tasks. Intellective tasks are problems or exercises that can be solved with correct answer. The correct answer can be easily identify by experts. For example, "This wall is too dark, which color would you choose to lighten it ?" is a problem which has not a correct answer. The third quadrant named 'Negociate' is composed of cognitive conflict tasks and mixed-motive tasks. Cognitive conflicts task is based on conflict of viewpoints (and not conflict of interest) whereas mixed-motive task consists in conflicts of interest like settings of scores. The quadrant 4 name 'Execute' gathers contest, battle, competitive tasks and performance tasks.These tasks particularly foster conflict of power. The main goal consists to win. These tasks are based on the competition to reveal the excellence.

The research exposed here is based on intellective tasks and decision making tasks. The group must act, communicate, make decisions facing a problem where the issue can be demonstrated.

4.2 Serious games

Many researchers or game designers tried to define what are serious games but like many other recent innovations, there is no ground on which a general consensus could be build. Then, the question of serious games encourage scientific debates.

Quite a few definitions of serious games exist. This point stresses the difficulty to get a global agreement from the scientific community.

Clark Abt [Abt1970][Abt1987] suggested since 1970 a definition of a serious game as the reunion of action and thought inside a game sequence. The game is a support and can in turn be broken down into game on computer, role-playing game, board game and even outdoor game.

4.2.1 Teleological approach

The teleological approach consists to study serious game according to their purpose. Thus, using this approach, the game designers Chen and Michael [Michael+2005] proposed in 2005 to define serious game as "‘Games that do not have entertainment, enjoyment or fun as primar purpose"’.

Alvarez [Alvarez2007] in 2007 enhanced this definition and defined serious game as an object which characteristics are:

1. It combines of video-game and one or more utilitarian features as broadcast a message, give a coaching, promote data collection...
2. It does not focus on the entertainment market but defense, education, training, health care, marketing or communication...

Benjamin Sawyer [Sawyer2007] defined serious games as “Any meaningful use of computerized game/game industry resources whose chief mission is not entertainment”.

4.2.2 Genealogical approach

Another approach consists in studying serious games from the birth of video games or birth of games. If we focus on the video game evolution particularly from the invention of the computer in the 1950’s to the video games console, the Internet and the mobile phone, we can notice that the games contents, their purposes, the usage modes and their consumption mode, the game market has moved forward very considerably during this last decade. The target audience is also larger than few decades ago [Fortin+2009].

4.2.3 Axiological approach

The axiological approach consists in studying the serious game regarding the values and information broadcast with this medium. From an axiological point of view, the serious games can broadcast moral values, ethics values, human values, cultural values, religious values... Sometimes misinformation, propaganda or publicity are the underlying goals on which designers build their scenario.

4.2.4 Empirical approach

The empirical approach consists in studying a large variety of serious games products, identify and gather their characteristics in order to classify them. In the field of library collection, the Dewey Decimal Classification (DDC) system is used to organize knowledge. This classification system tool is the most popular in the world. Libraries in more than 135 countries use the DDC to organize and provide access to their collections, and DDC numbers are featured in the national bibliographies of more than 60 countries. The system was conceived by Melvil Dewey in 1873 and was first published in 1876. The system features well-defined categories, hierarchies, meaningful notation and allow to build complex relationships to classify a resource. The Dewey Classification System provides hierarchical classes. As an illustration, the ten first classes of DDC are :

```
000 Computer science, information & general works
100 Philosophy & psychology
200 Religion
300 Social sciences
400 Language
500 Science
600 Technology
700 Arts & recreation
800 Literature
900 History & geography
```

Contrary to library collection where Dewey Decimal Classification allows to classify books, magazines. . . , the even though researchers tried to elaborate classification standard, there is no consensus to classify serious games. Similar problems occurs when experts want to classify music or movies or video-games [Djaouti+2011][Elverdam+2007][Apperley2006].

Those who studying existing serious games research characteristics as mode of development, offered contents, transmitted message, technology or technical approach used, the presence of scientific models or undeniable historical facts, the background of designers who composed the team. . .

Zyda [Zyda2005], Michael and Chen [Michael+2005] proposed a classification based on markets. To illustrate, According to Zyda [Zyda2005], a "'Serious game: a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives."'

Others like Bergeron proposed a classification based on purpose. Bergeron [Bergeron2006] classifies the purposes of serious games info seven categories: Activism games, Advergames, Business Games, Exergaming, Health and Medicine Games, News Games, Political Games.

And others propose a classification based on multi-criteria. This is the case of Sawyer et Smith [Sawyer+2008] who tried to introduce a global taxonomy which indexes Serious Games according to two criteria:

- Market: Government and NGO, Defense, Healthcare, Marketing and Communication, Education, Corporate, Industry
- Purpose: Games for Health, Advergames, Games for Training, Games for Education, Games for Science and Research, Production, Games as Work.

In an other research, Djaouti et al. [Djaouti+2011] proposed another model to classify serious game based on game-play, purpose and scope (G/P/S. Based on this model, the website http://serious.gameclassification.com/FR/ provides a request by this criteria. Criteria are purpose, market and public.

4.3 Learning games

Even though the definition of what is a serious game generates and encourages debates, the definition of what is a learning game may explain through an analogy to the place of the documentary movie in the cinema industry.

4.3.1 Characteristics

Digital learning games have a similar place in the video-game industry as documentary film in the movie industry. Basing our thoughts on a teleological approach, the main goal of learning game is educational and pedagogical. It aims to inform, communicate pieces of knowledge or make people experiment educational situations that facilitate skills extension, know-how development and abilities. The main purpose of learning games is not entertainment but learning and training that's why they embed pieces of knowledge or creative representation of professional contexts tuned to suit the pedagogical situation. As a result, their markets target both teachers/trainers, students/pupils/mentoree, schools, universities, training centers...

More than the purpose, the point is the relevance of the contents embed in the learning game.

For example; Assassin's creed is not a learning game even though their designers called historians to represent the virtual world as the most realistic as possible regarding the real existing medieval city. Its main purpose is entertainment but not edutainment.

More than the goals and the markets, the point is who made the educational content, who contribute to the content. Teachers ? Experts ? Do we place the same trust in digital environment in whose contents are deliver by experts in a disciplinary or in contents delivered by game experts ? Designing a learning game implies the contribution of recognized experts and teachers in the field whose the learning games focuses. Teams who designed a learning game must be composed of recognized experts in the field being teaching or/and expert in education or training. They must validate the educational contents.

Another approach which should give an important indication on the trustworthiness of the content consists in analyzing the distribution network. For example, if the game is distributed by Google Play, Microsoft or Sony Entertainment, public is likely to classify the game as an entertainment game and not an edutainment game.

As an illustration, in healthcare field, Trauma Center Second Opinion (Atlus, Nintendo DS, Wii), Trauma Center Under the knife (Nintendo DS3) and Dark cut 2 (http://armorgames.com/play/353/dark-cut-2) are three samples of entertainment video games which popularize as well as provide surgery information or medical techniques in a realistic representation. Both, they contains realistic medical procedures. They propose to play the surgeon in an exciting medical drama simulation. You'll need to cure patients from routine medical diseases or Civil War worst wounds. Your medical toolkit includes scalpels, forceps, syringes, whisky and more. These examples stress the importance of the questions : who made the game contents and which organization distributes the game. These two characteristics have a crucial impact on the confidence we place in the product.

The learning game is generally distributed by recognized training organizations and/or validated by educational experts or recognized educational organizations whose activity is mainly composed of education or training.

Another approach consists in studying the context the learning game is used and associated social practices.

A definition of what is a learning game should be: A Learning game is a creative representation of the reality basing on game mechanisms already approved by video-game industry combining with an educational scenario and providing feedback and learning analytic tools to create a coherent debriefing both for teachers and students. They embeds educational contents or pedagogical situations validated by experts in the field that the game focuses on.

A mathematical definition of a digital learning game is:

```
Video-game mechanism
        (game design - level design - sound design)
        +
 Educational and
 interactive scenario
        +
Learning analytics tools
(to the student and the teacher)
  =
Learning game
```

According to that point of view, the National Summit of Educational Games (Foundation of American Scientist) in 2006 pointed out attributes that are important for game-based learning: clear goals, repeatable tasks, monitoring of learners progress, encouraging increased time on task and adjusting the learning difficulty according to the learner's level.

Watkins et al. [Watkins+1998] note that serious games are able to contextualize play-learners experience and support cognitive experience.

4.3.2 Definitions connected to game vocabulary

In this report, some usual words are employed and their means might be ambiguous. The definitions below help to understand the implicit key-concepts.

Player Real human who uses a character in the virtual environment to train to manage a situation.

Trainer Real human who uses the virtual environment to monitor the virtual teamwork.

Objectives An objective can be defined as a success goal to achieve or a well-know failure state that can be achieve in case of successive mistakes.

Non-player character or Virtual human Virtual humans are software artifacts that look like, act like, and interact with humans but exist in virtual environments.

Avatar graphic representation of an actor in the virtual environment.

Character The character embed different characteristics as a role, a pseudo... His graphical representation is the avatar.

Role The role allow to connect a character to a set of available actions, available information, available files, documentation and objects on which the character can interact with.

4.4 Synthesis

Firstly, in this chapter, we have presented the basic and essential elements that designers take into account when they create a multiplayer virtual environment such as avatar's representation, universe, shared global goal and link between interactive objects, tasks and behaviors. We have presented the main constraints we need to deal with in the specific case of collaborative training in a complex socio-technical system. In such a context, tasks are non-linear and distributed between teammates. The notions of parallelism and synchronization in the teamwork activity are crucial. This point implies that there is a large combination of possible paths to achieve a common global goal. Furthermore, the context of risk management training implies to propose a global objective that foster collaboration and communication.

We choose here to refer to intellective tasks and decision making task. Intellective tasks are problems or exercises that can be solved with correct answer.

Secondly, some examples of virtual collaborative environments illustrate how the team activity could be represented. Among all virtual interactive and collaborative environments, some are designed to simulate with high fidelity a professional context for training purpose. Others have been designed for learning purpose and represent with creativity the real context in order to serve educational objectives. Virtual environments like serious games and particularly learning games, even if they are criticized, offer great opportunity in terms of training and learning. As a proof of that, learning games can combine both game design mechanisms, interactions validated in video-game industry and creative representation of reality that supports predefined educational objectives.

As part of this research, the virtual collaborative environment we work on will combine both game mechanisms and interactions that support predefined educational objectives of training in the risk management field.

Chapter

5

Designing an interactive scenario

Studying interaction design and interactive storytelling, there are many ways to design such a scenario. The scenario driven approach and the emergent narrative theory are the two main approaches in the field of Interactive Storytelling. Our work is based on the scenario driven approach using real surgery video records and experts interviews. The main reason is that we need to control the development of the situation and monitor the team activity. By means, we need to guarantee that the team activity keep the story in the field of the pre-defined scenario according to the initial educational objectives.

In this context, the next sections present a short and partial overview of methods, approaches and models that can be used to design an interactive scenario that will be played and monitored in a virtual collaborative digital environment.

5.1 Interactive Scenario

The online Oxford dictionary defines a scenario as "A written outline of a film, novel, or stage work giving details of the plot and individual scenes." The online Cambridge dictionary defines a scenario as "a description of possible actions or events in the future" or "a written plan of the characters and events in a play or film".

In the field of learning games, a scenario can be considered here as a set of elements :

1. a briefing : presentation of the current situation and expected objectives to reach : the mission
2. the virtual universe: objects, furniture, documents, characters...
3. a set of actions, pieces of information, documents, furniture and objects which can be manipulated throw the universe to achieve the mission
4. playful and educational lockers such as educational prerequisites, educational failures to avoid...
5. educational skills to develop or acquire
6. abstract or concrete concepts which can be manipulated with interactivity throw the environment: game play elements as inventory of assets, monetary system, virtual store... and educational concepts as programming, making decision...
7. steps or levels which compose the mission
8. educational objectives to reach (visible or not in a briefing stage)
9. a debriefing: summary of outcomes with feedback that should help the player to succeed in the future

The scenario proposes to the players a short storytelling of what is the actual situation and what is expected situation at the end. The scenario provides interactions that allows the players to achieve the mission and lockers (educational lockers or playful lockers) to prevent the player to succeed. The scenario can be broken into different steps. Each step presents another goals to achieve and intends to serve the main mission.

5.2 Scenario centered on tasks

The traditional "environment-centered" approach consists in an implicit distributed design where the possible experiment of a trajectory in the game is expressed throw the behavior of the objects. The main source of trouble comes from the absence of an overall coherence in the virtual world, as attaching a script to every object throughout the environment. It does not really allow to describe how these objects relate to one another, or how one interaction with an object is likely to change the states of other objects around (for instance, in the operating room, one immediately thinks of the patient and the monitoring equipment such as anesthesia machine).

Putting the tasks at the center of the design process is certainly an alternative way for facilitating the process of pedagogical design. This approach consists in explicit design where expert describes the process, the objects in the real world and the concepts manipulated. As the result, the scenario is divided into linear or no-linear tasks. It is composed of a set of predefined and non-alterable parameters expressed throw the model and predefined and alterable parameters expressed through the behaviors of the objects (character or equipment). This approach consists in previously studying and understanding the underlying concepts which must be manipulated throw the interaction. This is the case of Mecagenius, a learning game which embeds more than 200 educational activities in mechanical engineering. The environment is a creative representation of a real mechanical engineering workshop. The scene takes place in an spatial vassal in a far future. The hero must repair a vassal with materials he can collect succeeding mini-games. A mini-game proposes an interactive educational experience based on the professional activity using game mechanics, virtual machine tools and mechanical engineering concepts. The model offers representation of non-interactive objects and interactive objects with attached behavior[Pons Lelardeux+2015][Galaup+2015].

This kind of approach lets the player relatively free to act but the designers must identify any interactive object and describe any behavior of them. Obviously, it takes a lot of experience and there is no methodology to facilitate the process.

5.3 Scenario designed with ontology and tree-like structure

Using a tree-like structure to describe human activity is a widespread practice in virtual environment where an unique player is involved. In a tree-like structure, each arc represents a choice and each node represents the state of the world (see figure 5.1). For every state, the user has to make a choice between different alternatives. There is normally one best choice, with the other alternatives being either wrong, or not as good. This kind of scenario offers different pipelines and maintains the user in a entirely controlled session.

Barot et al [Barot+2013] who developed a Virtual Environment for Risk-Management Training Based on Human-Activity Models based their works on models to represent knowledge. These models intends to structure and manage knowledge. They use it to describe tasks inspired by two task-description languages developed in the ergonomics and Human Computer Interaction communities: MAD (Analytical model for task-description) and GTA (Groupware Task Analysis) [Sebillotte+1994][Van Der Veer+1996]. They have been created after the real-work observational study. The scenarios were designed to make the learner schedule their tasks, prevent from accident and perform their skills. The activity itself has been designed with the Hawai-DL(Human Activity and Work Analysis for sImulation-Description Language) [Amokrane+2008] and ACTIVITY-DL [Edward+2008][Barot+2013]: a language which allows to describe hierarchically tasks, available actions, errors. As the result, the description is based on a cognitive analysis of a task rather than logical analysis of a task. Using this method, a set of possible goals/tasks and subgoals/tasks are described in a hierarchical structure. This description translate the operator's viewpoint of the activity, the relations between the goals and the possible flow of actions and conditions of their achievement.

The design deals with the pedagogical objectives and the player's profile. Seldon (ScEnario and Learning situations adaptation through Dynamic OrchestratioN) aims to generate and control scenario within a virtual environment [Carpentier+2013].

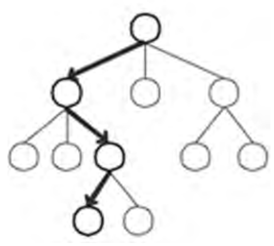


Figure 5.1 – Ontology

This approach consists in limiting interactions and control every paths you can travel in the universe. This method enforce the designers to describe every paths in a tree like structure. Branching scenarios are very fashionable nowadays in e-learning applications but it reduces the freedom of action in the virtual environment.

A branching scenario is designed like a tree structure where every action from the player leads to selecting a branch. Responses from the environment or the virtual characters can be inserted in the scenario using the same structure. However, the approach is not suited for a multiplayer experience. This technique is basically used to design branching dialogues for example. This is the case of the interactive dialog editor Serious Talk (by Succubus Interactive company) [Interactive2016].

Interactive storytelling [Göbel+2009] [Porteous+2010][Sanchez+2004] extends the scenario modeling possibilities and makes use of artificial intelligence planning to manage the dynamic progression of the scenario. In both cases, the approach works well for one unique player but is not applicable to multiple players. Indeed, multiple players and rich player expression reduces the ability for the author to think ahead and model every situation, note Rield et al. [Riedl+2011], and therefore it is foreseeable that the scenario will derail at some point. They propose to enhance a non-branching narrative with a Petri-net based system creating branches on demand to handle the exceptions.

On one hand, this model is not a feasible solution to design multi-player activities due to a probable large number of combination. On the other hand, the exchanges of pieces of information are not included in the process.

5.4 Scenario represented with Petri Nets

A game scenario is divided into different successive levels. A level can be reached if the player won the lower one. Each level is characterized by a sub-objective, barriers and possible issues. Player's possible actions are atomic transactions. Petri Nets can be used to specify the transactions and describe the storyline.

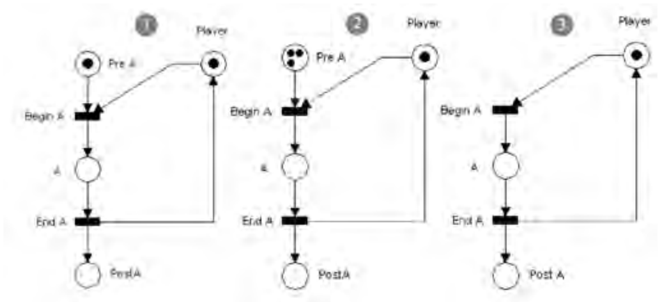


Figure 5.2 – Petri Nets allow to specify how many executions is possible. The Petri Net '1' indicaes that only one execution is possible. The Petri Net '2' indicates that three executions of the transaction A is possible. The number of execution of the transaction A in the last one is infinite.

A Petri Net is a directed bipartite graph composed of two kinds of nodes: transitions and places. Transitions is an event that may occur which is graphically represented by a bar. Place is a condition which is graphically represented by a circle. An arc runs from a place to a transition and from transition to place.Using this models, designers are able to define pre-condition and post-condition to a task.

A Petri Net is a four-tuple defined as follows:

$PN = (P, T, F, W, M_0)$ where P is a finite set of places $(p_1, \ldots, p_n)$ where $n \in \mathscr{N}*$ T is a finite set of transitions $(t_1, \ldots, t_k)$ where k $\in \mathscr{N}*$ the places P and transitions T are disjoint: $P \cap T = \emptyset$ $(F) \subseteq (PxT) \cup (TxP)$ is the *flow relation* W is an input function $W : F \to \mathscr{N}*$ is the arc weight mapping $M_0 : P \to \mathscr{N}$ is the initial marking representing the initial distribution of tokens

The W function refers to 2 functions : a pre-set function and a post-set function.

If $(p, t) \in (F)$ for a transition t and a place p, then p is an *input place* of t. If $(t, p) \in (F)$ for a transition t and a place p, then p is an *output place* of t, Let $a \in P \cup T$. The set ${}^{\bullet}a = a'|(a', a) \in (F)$ is called the pre-set of a, and the set $a^{\bullet} = a|(a, a') \in (F)$ is its post-set.

Natkin et al [Natkin+2003][Natkin+2004] show how Petri Nets can be used to organize and structure a video-game scenario describing ordered actions.

Thomas et al. [Thomas+2012] provide to serious games players an automated tool for monitoring and analyzing their actions performed by learners. Their system combines Petri Nets and ontologies.

Petri Nets are particularly suitable to represent asynchronous and concurrent systems. This is the case of multi-player and turn-based games. The game Europe 2045 is such a learning game that propose to players to manage a country in Europe [Brom+2007]. Each participant can elaborate laws, distribute subventions or taxes and see the consequences of their decisions on the Europe Community. Brom et al. [Brom+2007] use Petri nets to represent every possible paths corresponding to all the available decisions that can be made by the players in the game Europe 2045 (see figure 5.3).

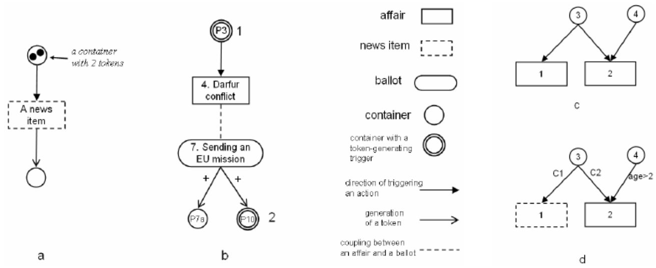


Figure 5.3 – Europe 2045 is a multi-player turn-based game designed with Petri net models [Brom+2007].

A large variety of Petri Nets is available: temporal Petri Net, colored Petri Net, object Petri Nets could be suitable to represent a teamwork activity. The main advantage to use it is that mathematical properties of Petri Nets can be used to check and validate the coherence of a scenario designed with a set of Petri Nets. On the other hand, their graphical representations might not facilitate expert's validation (especially game designers, medical staff and nurse staff involved) and could have a really negative impact to check and validate contents of a complex scenario involving three or more players. As a consequence, we did not use Petri Net to design the interactive scenario and represent the teamwork activity.

5.5 Scenario designed with Linear Logic

Some researchers intend to provide tools to help game designers and experts to create interactive scenario and manage interactive storytelling. These tools are based on linear logic that provides strong mathematical algorithms to calculate and deduce results. Their aims consist in controlling three main points: (1) there are enough options in the scenario to make players feel that they are responsible of the course of play, (2) the scenario respect all the initial constraints (narrative key-points, issues. . .) (3) the representation of the scenario is executable.

Prigent et al.[Prigent+2007] and Collet et al.[Collé+2005] identified the characteristics of a scenario to observe :

- reach-ability

- no deadlock
- fairness
- complexity

Following this research, Martens et al. [Martens+2013] explore the use of Linear Logic for story generation. Based on proof-term obtained from the story instances, they build a graph where nodes are narrative actions and edges represents inferred causality relationships. Bosser et al. [Bosser+2010] propose to model resources involving predicates, initial conditions, actions... and the constraints linked to the end of a story. They use a tool named "'Coq"' to analyze the structure of the obtained scenario. As a consequence, they can check if the scenario observe the constraints, respect the initial criteria of narration and check if all the issues can be reached.

Following the same objective, Dang propose [Dang2013][Dang+2010] a model, a method and a tool to model and validate Interactive Storytelling using linear logic. They propose a meta-model of narrative storytelling and experiment it on two examples. The first step of the methodology they adopt use an authoring tool that produces a scenario in Planning Domain Definition Language (PDDL). PDDL [McDermott+1998] is a language employed to specify the behaviors based on scheduling models. This language is used by a large number of tools dedicated to management of interactive scenario based on artificial intelligence.

5.6 Model based on resources

Another approach consists in designing interactive scenario basing on behaviors and resources. This is the case of scenario designed for Real-Time Strategy (RTS) video games. Lemaitre et al. [Lemaitre+2015a][Lemaitre+2015b] propose a resource-based model of strategy to help designing opponent AI in RTS games. They defined a behavior as a set of behaviors or primitive tasks, its type, and the resources needed to realize the task. They classify behaviors in two types: parallel and logical. A parallel behavior requires additional attributes as how the resource must be distributed and the associated sub-behaviors. A logical behavior requires additional information about the decision-making process and the associated sub-behavior for each execution.

```
A logical behavior is represented by a tuple by a tuple <B, M, SB, CB> where:
B is the set of sub-behaviors
M is the set of triggers <OB, T, DB>
SB is the starting sub-behavior
CB is the current sub-behavior
```

Lemaitre et al. illustrates through an example the use of a logical behavior. Three sub-behaviors of a NPC are identified: Explore, Fight, and Gather. They define Explore as the initial sub-behavior, then if enemies are encountered or food is found during the exploration, the sub-behaviors Fight or Gather, respectively, are selected. They represent the expected logical behavior as follow:

```
B = {Explore, Fight, Gather}
M = { <Explore, SpottedEnemy, Fight>,
<Explore, SpottedFood, Gather>,
<Fight, Success, Explore>,
<Gather, Success, Explore>,
<Gather, SpottedEnemy, Fight> }
SB = Explore
CB = Gather
```

5.7 Adapting and re-using an existing environment

Another method consists in using an existing virtual environment with an existing game engine which provides and manage the same concepts as the designers want to reproduce. One drawback of using an existing virtual environment is that scenario authoring is far from intuitive, although Bellotti et al. demonstrate how a virtual world can be enriched with authored educational tasks and therefore turned into a serious virtual world [Bellotti+2010].

5.8 Experimental approach to design a scenario with autonomous agent

Other techniques have extended ExploreNet's logic. The object-centric environment of ExploreNet is composed of many objects, some of them being interactive props endowed with an autonomous behavior (this includes the non playing characters), and others merely backdrop objects. Finally, the behavior of an object can be triggered by means of clicking an action label visually attached to this object. In the multi-agent system used in the learning game Format-Store[Mathieu+2012], every single object in the environment – whether character, item or furniture – is modeled like a software agent and therefore endowed with an autonomous behavior. As a result, the interactions between multiple human players, non playing characters, items and the environment are easy to model and offer a great potential in terms of adaptivity and expressiveness. However, scenario authoring, even if possible, suffers from the same shortcomings than the other approaches centered on the environment.

Recently, Orkin et al. have described an original approach in [Orkin+2007] where a fully interactive environment, namely a virtual restaurant, is made accessible for thousands of human players to explore freely. Based on the collection of their actions, a machine learning approach is applied in order to build the statistically-realistic behavior of the virtual employees. Provided that enough training is applied (i.e. enough sample data is collected), this technique shows very promising results. Although it is not possible to design a scenario per se, this technique should allow training one or several artificial characters to imitate a human tutor.

5.9 Business Process Modeling and Notation (BPMN)

In the context of team training, we need to model, control and monitor both individual activity and teamwork activity. To the end of modeling parallel, distributed and synchronous tasks, our interest focuses on Business Process Modeling and Notation.

Business Process Modeling and Notation graphical representation [White2004] [Allweyer2010]. "BPMN defines a Business Process Diagram (BPD), which is based on a flow-charting technique tailored for creating graphical models of business process operations. A Business Process Model, then, is a network of graphical objects, which are activities (i.e., work) and the flow controls that define their order of performance."[White2004]

The syntax of the BP Notation is simple: rectangle-shaped boxes represent activity nodes, circles represent event nodes and edges represent flow sequences linking nodes to each other. Each BPMN diagram describes a sequence of activity, where activity nodes are arranged in several lanes, representing different roles, inside a pool. It is designed and read from left to right chronologically. A unique "Start" event node represents the entry point of the sequence. One or several "End" event nodes represent the outcome(s). In between, activity nodes are connected with one another by flow sequences, establishing a relationship of order which should not necessarily be interpreted as a strong constraint. For instance, A→B does not mean that A must be completed before B. It merely indicates that, with respect to our observations in the OR, A has always (or most of the time) been completed before B. However, if nothing prevents completing B before A, then the player re-enacting this activity should be allowed to. Of course, the question is irrelevant if action B is "physically" or logically impossible unless A has been achieved. This question is addressed when connecting the actions and the environment, in section 11.2. Modeling situations more complex than unconditional linear plans of actions is possible using another element of the BP Diagram syntax: gateways. Basically, we used two of them: the parallel gateway (+), for coordinated activity, and the exclusive gateway (×) to express choice and alternative. A gateway can be found after one action and opening to several actions or paths of action. In that case, it means the activity is about to face a collaborative sequence (parallel) or alternative paths (exclusive). When the sequence is over, another gateway is placed to mark the end of the sequence. This one acts like a control barrier and the activity cannot be carried on unless one path (exclusive) or all the paths (parallel) has/have been followed first.

A pool represents a Participant process. It is represented as a graphical container that contains a set of activities or tasks.

A Lane is a sub-partition within a Pool. Lanes are used to organize and categorize activities or tasks (see Fig. **??**).

As an illustration, the figure 5.4 exemplifies the interaction between the doctor's office and a patient.

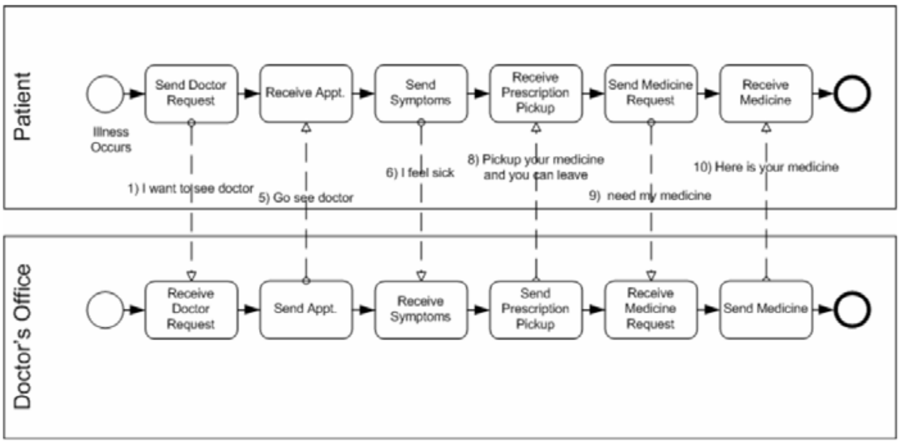


Figure 5.4 – BPMN Diagram represents in a pool a process between the patient and the doctor's office [White2004]. The first lane contains the first participant's activity and the second lane contains the doctor's office activity.

This model enables to represent in a collaboration diagram the message flow between two or more participants (see Fig 14.1). Parallel tasks, synchronous tasks, exchanges of piece of information can be graphically represented on diagrams. This model presents the advantage to be easily understandable even by lay public. This point should facilitate the checking and validation steps in which a large variety of professionals will be involved.

5.10 Synthesis

This chapter suggests a partial overview of models, approaches and methods to design an interactive scenario. Some designers manage the scenario design basing on behaviors, tasks or/and resources using Ontology, Tree-like Structure, Petri Nets, Linear Logic. Other researchers use artificial intelligence algorithms to manage and control autonomous agent behaviors.

In this thesis, we choose to focus on Business Process Modeling and Notation to model teamwork activity and plan to use it to design interactive collaborative scenario. The main reasons are: (1) the ease to model collaborative, parallel, distributed and synchronous tasks and (2) the representation of the teamwork on graphical diagrams that could be easily checked and validated by lay public.

Chapter

6

Communication

6.1 Communication and situation awareness

6.1.1 Communication

Human interactions are based on communication. Keyton et al. [Keyton+2010b] 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 [Keyton+2010a] 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 co-construct meaning". Here, the word communication refers to macro-cognition.

The kindness and the expertise of the sender are the two main axes which have an impact on the evaluation of the information by the receiver [Fiske+2007].

The degree of confidence depends on the links between the sender and the receiver as social links : family, friend, colleague, and social status: professional status, ages.... Many factors impact the degree of confidence we accord to the others. According to this degree of confidence, the receiver value the quality of the information broadcast.

6.1.2 Situation awareness

Situational awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status into the near future.
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 [Endsley1995] 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 [Kaber+1998] 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".

6.1.3 Team Situation awareness

Team Situation Awareness (TSA) is one of the critical factors in effective teamwork that can impact the success of the final achievement. Mathieu [Mathieu+2000] showed the influence of shared mental models on team process and performance by testing 56 undergraduate dyads who train on flight simulator. Another important factor is the role of expertise in a dynamic system [Devreux+2014].
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.

6.2 Communication in a virtual environment

From reality to virtuality, many different kinds of educational environment are used to teach knowledge and skills. The figure (ie: see fig 1.5) presents different training contexts. The horizontal line represents on the left extremity a training situation which is entirely virtual and on the right extremity the real professional environment where learners can see and interact in a real-life situation. On the right extremity, the situation can be compared with coaching or mentoring relationship between the learner and the professionals. In these contexts, the learner can see how the professional interact and manage their tasks. They can share their thoughts, learn one another and build a climate of trust where the learner can develop their skills facing to real tasks in a real working context. Thus, the mentoree can feel secure in sharing the real issue that impact his/her success. Furthermore, the professional can guide and provide feedback on areas in which the mentoree is in need of coaching. In these situations, professionals play both the role of a mentor and a coach. They help the learner to develop their skills facing to real-life professional situations. Among all these training situations, we will focus on those in which learners need to talk either with real human or virtual human to develop soft skills.

First of all, 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 modeling.... Even though, the field of communication is very large, we mainly focus on verbal communication excluding facial animation, gesture, emotion, movement and body animation.

Firstly, this chapter presents environments in which a human and a human or a human and a character controlled by a computer (CCC) have to communicate either in a cooperation relationship to achieve the same goal or in a competition relationship. Secondly, it shows how technologies and artificial intelligence deals with communication and collaboration skills in virtual environments for training where humans are expected to develop these skills. We will illustrate the current issues with different examples of virtual environment designed to be used in a learning context where learners can talk either with real human or virtual human. Thirdly, the next aspect we consider is the question of rules and representation we need to reproduce to foster communication and teamwork through a virtual environment. The question of traceability is the main point to take into account to design collaborative virtual environment for training.

6.2.1 Human-like communication between a human and a computer-controlled character(CCC)

The communication can be established using with different media. The medium used to communicate depends on the actors who need to discuss together. The figure 6.1 presents different situation where communication need to be established between a machine and a human or two humans who use a collaborative training environment.

One-way communication : CCC to an human

Virtual digital worlds use generally at least one-way communication to make non-player-character (NPC) communicate with a human/player. In that case, the only character who speaks to the player's character is a CCC. They can be graphically represented by an avatar as an embodied conversational agents [Cassell2000] or an animated pedagogical agents and talk with the player combining facial animation with text timed-scrolling system while re-recorded voice can be heard. Animated pedagogical agent use facial animation or gesture (see fig. 6.2) to indicate their agreement with the student's actions. They can present for example a look of puzzlement when the student makes an error, and shows pleasant surprise when the student achieve a task. Johnson et al. had set forth the key features that lifelike agents will need to succeed at face-to-face communication [Johnson+2000].

But most of the time, designing character's facial animation with avatar's authoring tools remain cumbersome [Pandzic+1999]. Thus, none avatar might represent the NPC and the text timed-scrolling system is the only support of communication between a player and a NPC. In this case, the GUI displays only the speech to brief and debrief the human on what is expected or what's going on or simply deliver a message.

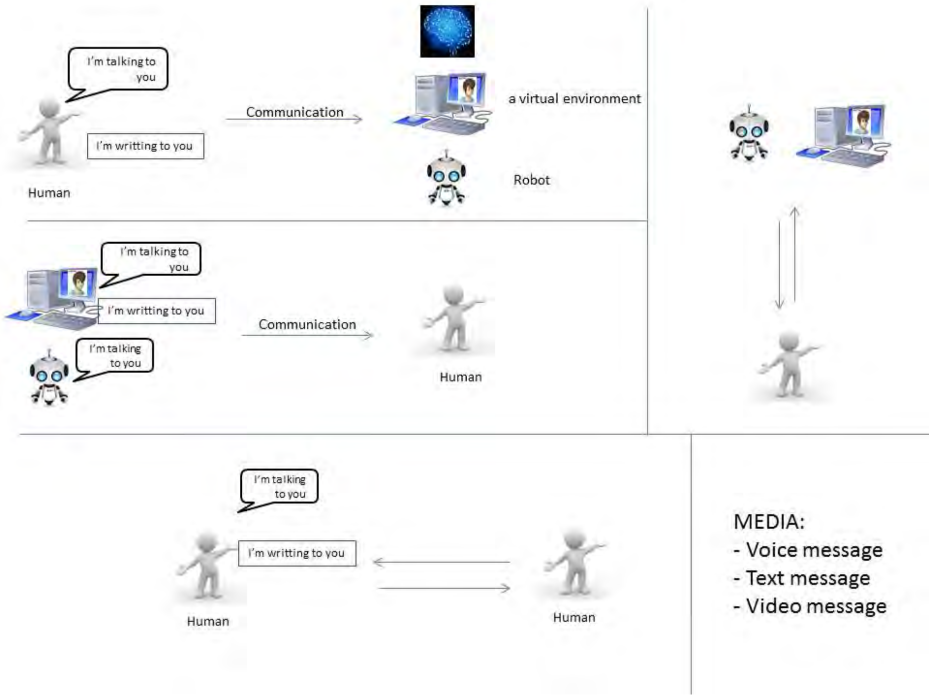


Figure 6.1 – Medium and communication with/in a virtual world

Figure 6.2 – ADELE - An animated pedagogical agent [Johnson+2000]. She is able to point toward objects on the screen, and can also direct her gaze toward them;

Mateas and Stern [Mateas2002] [Mateas+2003] [Mateas+2004] described the environment Façade based on artificial intelligence algorythms. In this drama, the player writes text to discuss with NPC and the NPC communicate with them using natural language which is subtitled too.

Another example is the case of Agile Doctor [Guo+2014], a serious game to improve communication between a doctor and their patients. The trainee plays the role of a doctor in a face-to-face conversation with a virtual patient. The conversation structure is composed of 3 elements: phases, dialogue sessions and phrases. A conversation engine retrieves the dialogue session and provides possible sentences to the trainee to go on the conversation. The scenario is based on ontology to describe the patient's profile, the result of a medical consultation and the sentences to build the dialogue.

Another example is the video-game "Rachet and Clank" (Insomiac Games - Sony Computer Entertainment) which is available on Play Station 2, 3 and Play Station 4. In this game, the player manipulates Rachet, a lombax who helps a little robot Clank to save the galaxy in the science-fiction universe. They try to get assistance from Captain Qwark against Drek who wants to destroy all the planets to save the Blargs' species. "Rachet and Clank" is a first personal shooter game which proposes to the player to use a large variety of weapons and war artifacts to destroy the enemies. The communication between the player and the other characters takes place since the introduction that presents the storyline the player. The speech is displayed on the screen while the voice can be heard (see fig. 6.3). The game uses this kind of communication all along the adventure.

Figure 6.3 – Rachet and Clank -Play Station 4 - The player can listen and read the character's speech

Two-ways communication : a human to CCC and CCC to a human

In the case of two-ways communication between 2 characters, a human can talk to a CCC and the CCC can talk to the human who plays the second character. Most games focusing on communication skills and team-working knowledgeably use a voice-chat system or/and text-chat to support communication between teammates. Using these system, they give up on the possibility to automate even partially the debriefing. The communication system that intends to support conversation between a human and a CCC implies to recognize words/sentence/text or audio speech to deliver coherent conversation from the CCC. But, 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. Besides, related domains of application like embodied conversational agents, which are virtual agents able to demonstrate verbal and non-verbal communication [Cassell2000], and conversational intelligent tutoring systems [Rus+2013] have reported significant advances in natural language processing techniques, and the benefits of using them are increasingly advocated [Hennigan2012]. In spite of the difficulty, one successful usage of natural language understanding in a game must be noted. In the game Façade [Mateas+2004], the player can talk naturally to the non-playing characters (NPCs) and get an appropriate response most of the time.

Current automatic speech recognition systems are mainly based on finite-state grammars or statistical language models like N-grams, which achieve good recognition rates. However, they have specific limitations such as a high rate of false positives or insufficient rates for the sentence accuracy. With the N-gram, the automatic speech recognition determines the dependencies between a word and the (N-1) preceding words. It searches and measures in a generated graph what is the hypothesis that fit to the best score. The Automatic speech recognition systems use mainly limited vocabulary and comes with a speaker-independent acoustic-model. Even though the speech recognition restricted to a limited vocabulary, or microphone quality…

The Aldebaran's robot named NAO is a good illustration of a conversation between an human and a robot that embeds a spoken dialogue system and behaviors system to mimic human gestures and communication[Heinrich+2011].

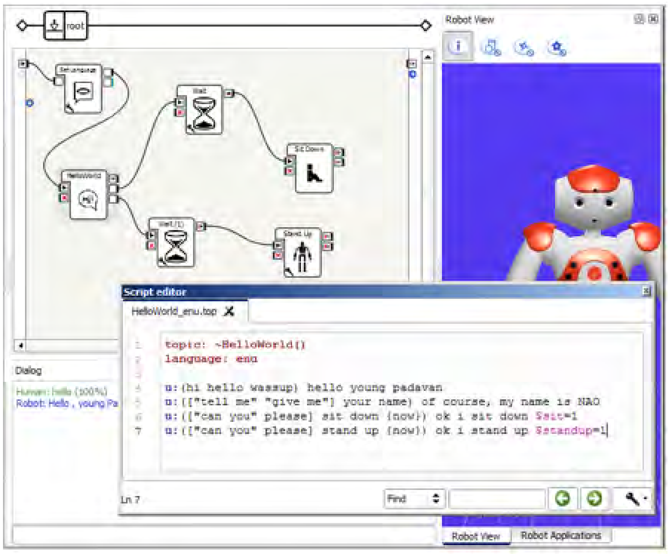


Figure 6.4 – NAO - A robot to talk with

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 [Tear2002].

Just-Talk [Frank+2002][Hubal+2004] is a role-playing environment with responsive virtual humans to train law enforcement personnel in dealing with people who present serious mental illness. The virtual humans mimic the linguistic, cognitive, emotional, and gestural components of behavior for paranoid, schizophrenic, suicidal-depressed, and normal virtual humans. Just-Talk uses natural language processing and virtual reality technology to demonstrate that experiences are realistic and engaging. The trainees' verbal inputs are analyzed and allocated to categories as queries, requests, commands, insults. . . and the virtual subject responds both vocally, with gestures and body (head, facial expressions as eye gazing or blink, open eyes, mouth open wide. . .) movement to the inputs[GuyeVuillème+1999]. They develop a behavior engine which combine gesture map, reply mode map and emotional states. They use language grammars that captured a range of syntactic structures and semantic categories. For virtual human output, they devised an extensible method of labeling phrases that increased productivity, complexity, and capability for reuse.

Mission Rehearsal Exercise(MRE) system [Swartout+2006] is a military training virtual environment that intents to demonstrate the use of virtual human technology to teach leadership and negociating skills in high–stakes social situations. The system allow the trainee (who plays the role of a soldier) to interact freely through speech with 3 characters (virtual humans: sergeant, medic and mother). The system embeds a speech recognizer, a natural language understanding (NLU) module, a natural language generation module. The speech recognizer module contains a vocabulary of few hundreds words and is able to recognize 16 000 utterances. Their NLU module can produce semantic representation frames for the sentences and a natural language generation module can express goals to achieve.

Link et al. [Link+2006] provide a responsive virtual human to teach phone-survey interviewers refusal avoidance skills. The application uses speech recognition and a behavior engine to produce natural dialogues with the trainees. The speech recognizer uses a basic dictionary of common words as well as a specific dictionary for each turn of a conversation. The specific dictionary consists of up to 200 words based on behavioral observations of real world events. These specific dictionaries are dynamic, therefore, changing with each turn of the conversation.

Another example can illustrate virtual team training environment via computer-based agents. This is the case of the virtual operating room of the LivesLab project. This virtual operating room is a fully immersive virtual environment and expects to enhance procedural surgery training using a Laparoscopic simulator. This virtual operating room is composed of real tangible objects as commercial simulators and virtual equipment. The communication system used is based on verbal communication with text-to-speech module and speech recognition module [Baydogan+2009].

Another one is the Training ED and hospital staff (physicians and nurses) to implement a “code triage” [Heinrichs+2008].

Other times, international companies deploy a virtual learning environment to train their teams to sell their products. This is the case of “Disney Stars” [2012] and ”Boostez vos ventes”(edited by Edit-Up-KTM Advance) which are french learning games. “Disney Stars” is a learning game designed to train travel agency workers to sell resorts and entertainment package to visit Disney World. The trainer plays the role of a seller and have to engage a virtual dialogue with a client who wants to buy a trip in an entertainment attraction park. Its educational objective concerns mainly managing a selling and adaptive conversation depending on the client’s profile. At the end, the seller has to propose the most suitable package to the client.

“Boostez vos ventes” is a learning game that intents to teach skills to sell products. The player takes the role of a seller in a store and has to collect information from the client who is an artificial character. The player needs to identify the client’s profile to propose him the best products according to their needs. The player chooses at any conversation step the message they want to send to the client. By this way, the player gathers information he can use to consider the client’s profile or the products to sell and propose products available in the store. The communication system is based on predefined sentences. The dialogue between the client and the seller is entirely scripted in a tree-like dialogue.

The communication features branching dialogues presumably written by or with the assistance of domain experts. When conversing with a non playing character, the player must choose between a set of pre-written sentences which are questions expected to be relevant to the situation, or answers that must be carefully chosen. The dialogue with the character is scripted so that any choice leads to another, in a tree-like manner.

6.2.2 Communication between 2 humans using a virtual environment

Both digital multiplayer games and virtual environment for training provide both a large variety of communication systems which allow teammates to plan a common strategy or to discuss to understand what’s going on or to collaborate to achieve a common goal. The virtual environments in which humans have to cooperate or to come face to face provide different kinds of features. The figure 6.5 present different available features.

The communication between two humans who use the same virtual environment at the same time can be established either inside either outside the environment. Any communication established outside the environment get out of control. As a consequence, the information broadcast can not be explored to assess a success or a failure. Some games use social networks as Snapchat, Facebook, Sony Entertainment Network to help player to discuss, cooperate, exchange goodies or strategy, visit others virtual worlds, challenge each others or build a team to achieve a mission in game. This is the case of ’Age of Ice’(a fantasy social game

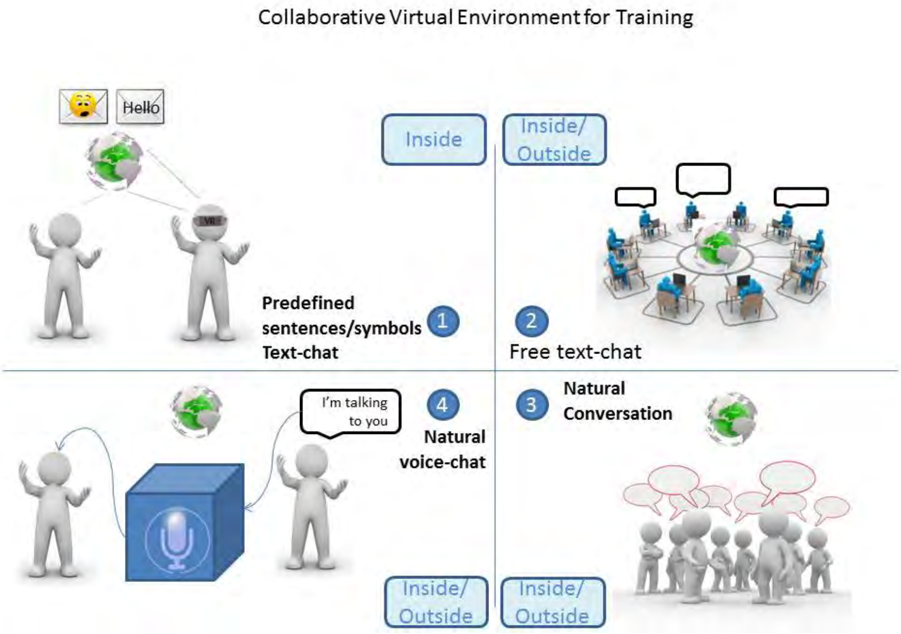


Figure 6.5 – Communication in a collaborative virtual world

developed by Artificial Mind and Movement and edited by Ubisoft), 'Call of Duty' (a war game edited by Infinity Ward), FarmVille (developed by Zynga) and many others. Others use dedicated forum or chat-room only available to experimented players. In this case, the assessment does not focus on the communication but only on the deployed strategy resulting from the communication.

Bubble of information

Some communication systems allow users to send bubble of information or comments to other players. This is the case of the mobile game "Clash Royale" (an epic strategy game edited by SuperCell) which is a multiplayer online battle arena (MOBA) inspired by "Clash of Clans". Player can clash with another player who is automatically selected by the game engine. Each player owns 3 towers: a king tower and 2 crown towers that compose its dungeon. In a battle, a player must attack another kingdom which is controlled by another player and the party takes 3 minutes in average. In case of successful clash challenge, the winner collects cards that represents character's who compose their deck of cards, money and gems to enhance their team and become more powerful. So, the players owns a deck of cards and can select and deploy some characters to fight the enemy's dungeons and defend their kingdom. The money helps the player to enhance their character's capacities as life power, damage capacity, damage per second, velocity, impact and range. In case of failure, the player loses some crowns. The time is used to give rhythm to the battle delivering elixir points which are spent to deploy new characters on the battle field. The communication between 2 players is minimalist and can be use all over and at the end of a clash to exchange comments or congratulations on the ongoing party. Bubbles of comments and emoticons are available and can be sent to the enemy (see fig. 6.6. This system is not designed to support a dialogue neither a coherent conversation.

Figure 6.6 – Clash Royale - Two players fight each others selecting their most powerful character's and deploy a strategy of battle. All over a party or when challenge ends, the players can send to each other bubbles of predefined text to the enemy.

Chat-system

Chat systems are easier to manage since the voice recognition stage is unnecessary. Moreover, chat is less natural, less efficient, since at least voice-chat keeps the hand of the player free for actually playing the game. They are very common in games. Historically, Lucas film's Habitat [Morningstar+1990] 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 [Johnson+2008], one can converse with a virtual patient in order to investigate their condition and formulate a diagnosis. However, understanding the content of text-chat still remains a problem that prevent from assessing the quality of information exchanged in a context that becomes totally uncontrolled.

This is the case for Clinispace [Parvati+2011] (Innovation in Learning Inc.) and 3DiTeams (Duke Medical Center and Virtual Heroes) [Taekman+2007], two learning games for healthcare training. Collaborative training implies communication features to help players understanding what is going on and exchange information or plan strategies. Clinispace uses voice an text-chat to allow players to communicate and displays at the top of the screen any actions made by the other characters mentioning the date-time. Inside these training environment, 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.

Another example concerns more particularly technical training in the field of industrial manufacturing and maintenance. On a virtual plastic injection press, players have to change a mold. This operation need to be managed by two operators. Their actions need to be synchronized, so, they need to communicate. Corvette (Collaborative Virtual Environment for Technical Training and Experiment)[Lopez+2014][Saraos Luna+2012] is the virtual environment where humans use virtual reality technology to learn industrial maintenance, complex process, security, diagnostic. . . . Two humans or a human and a virtual character collaborate to achieve a common goal and they use their voice to communicate as they are in the same room.

6.3 Fostering the communication

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

6.3.1 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 [Grice+1975] 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. Some 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 [Duranti1997].

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 [Sacks+1974]. 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 [Duncan Jr1973][Goodwin1981].

The communication system described here 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.

6.3.2 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 [Fraser1997].

Sometimes, the Wizard of 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[Tear2002]. Fraser et al. [Fraser+1991] 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 [Tear2002].

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[Navarathna+2010], Audio-Visual Speech Recognition (AVSR) is one of the advances in Automatic Speech Recognition technology[Mirzaei+2013][Lipovic2011]. It combines 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.

6.3.3 Text-chat systems

Among the large variety of verbal or textual communication system available on the Internet or in digital games, 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 [Herring1999]. 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 [Herring1999] 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 system available on mobile phone or tablet. 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.

However chat room conversation cannot be controlled easily to automate a debriefing on what was wrong or right during the training session. In a chat room, the conversation topic is free and no one controls 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.

6.4 Synthesis

Firstly, in this chapter, we have presented the definitions relative to communication and the theoretical concept of team situation awareness. It is important to highlight the importance of communication to build the most realistic as possible representation of the dynamic situation. In our research, communication refers to information exchanges. 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 modeling. . . . Even though, the field of communication is very large, we mainly focus on verbal communication excluding facial animation, gesture, emotion, movement and body animation.

Secondly, we have presented throw different examples digital and virtual contexts where communication between two people is part of available features to achieve a mission. However these contexts can be extremely different: environments where a human communicate to another human, environment where a human and a character controlled by a computer (CCC) have to communicate either in a cooperation relationship to achieve a common goal or in a competition relationship.

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, by voice chat or naturally speaking (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

Communication systems used to support cooperation can be divided into two groups: those which are completely integrated to the software and those which are dissociated. Speech recognition, text-chat, voice-chat, web forum, chat-room. . . are some examples of issues that can help to support information exchange. Except voice recognition technique (speech-to-text and text-to-speech techniques), they offer great features to mimic a dialogue leaving complete freedom to choose a conversation topic or information to exchange. However voice recognition can not assure fluidity of information flow in a conversation between three persons at least. Moreover, these techniques seem to be uncompetitive with a large dictionary. When virtual environment provides communication system that supports communication between users, some features have been identified such as:

- send a message with an information bubble (text or icons like emoticons)
- send text-message with a free text-chat
- build a text-message with predefined words
- speak naturally
- send a video-message
- send a graphical or sound message (set a flashing element on a map, ping a map for example or send a sound alert)

The table 6.7 synthesizes the different communication channels provided to users in different contexts.

In our case, the dynamic context imposes to promote real-time systems of communication. Even if text-chat, chat-room or forum offer freedom and flexibility, information exchange is extremely complex to monitor in real-time. It is important to note that most of the studied environments propose communication features that do not enable monitoring information exchange except those that entirely describe communication throw dialogue-tree. The main inconvenient using the dialogue-tree relates to the limited number of combination that can be manually described. Higher the number of participants in a conversation is, higher the number of possible combination is. Moreover, the number of combination also depends on the quantity of pieces of information the participants know. As the result, the dialogue tree representation is definitely not a good technique to use to support communication between more than two participants who need to manipulate a large number of information.

				Communication		
Category	Systems	Support	Application context	virtual agent to human	human to virtual agent	human to human
Video-game	Rachet and Clank (PS4)(2017)	video-game console	Adventure game	X (speech-to-text and virtual voice)		
Game	Clash Royale \Clash of Clans (2017)	mobile phone	Fantastic battle Game			X (message sent with bubble that contains predefined sentence. Emoticons message)
Embodied conversational agent interfaces	Rea (Cassell et al, 2000)	computer		x (verbal communication)	x (verbal communication)	
Animated pedagogical agents	Adele (Johson et al, 2000)	computer-desktop plateform	Medical education	x(text and graphical pointer)	x(button to ask question)	
	Agile Doctor (Guo, 2014)	computer	Medical education	X (predefined phrases) Text	X (predefined phrases) Text	
Robot	NAO (Alderaban robot)	Robot		x (verbal communication)	x (verbal communication)	
	Just Talk (Franck et al, 2002)	computer				
Embodied conversational agent interfaces	Mission Rehearsal Exercise (Swartout et al, 2006)	computer	Military social education	speech (dictionnary)	speech (dictionnary)	
Responsive virtual human	(Link et all, 2006)	computer	Phone-survey interview	verbal communication (text-to-speech dictionnary)	verbal communication (speech-to-text dictionnary)	
	LivesLab (Baydogan, 2009)	computer and tangible objects	Surgical education	x (verbal communication)	x (verbal communication)	
Serious game	Disney Stars (2012)	computer	Marketing and tourism	X (predefined phrases) Text	X (predefined phrases) Text	
Social Network	SnapChat	mobile phone				x (video-chat, text-chat, emoticons message)
Social Network	Sony Entertainment Network (2017)	Console				x
	Habitat (Morning Star, 1990)	computer				Text-chat
serious game	Clinispace (Parvati, 2011)	computer				voice and text-chat
	Corvette (Lopez, 2014)	computer VR	Manufacturing and maintenance	x (verbal communication)	x (verbal communication)	x (voice)

Figure 6.7 – Synthesis: analysis of communication features provided in different categories of environment

Thirdly, fostering and supporting communication in a digital and real-time environment implies respecting some implicit rules.

The communication system described in this report proposes features to allow avatar's conversation. It is be based on the implicit rules of face-to-face 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)

Chapter

7

Group decision making

7.1 Decision making

Training a team on risk management and particularly on risks linked to human factors implies to understand, foster and mimic the group decision-making process. The next sections intend to define first what is a decision and what is the group decision process. Secondly, we present different situations which foster a group to discuss and choose an issue facing to a problem. We present the role of reasoning, argumentation and leadership during the decision-making process. Thirdly, we present different samples of virtual environment which intend to make users cooperate to decide something that have an impact on the future events.

7.1.1 Definitions

The common definition of the word decision does not raise currently an issue however different research streams focus on decision-making. Here, the word decision refers to the process that leads the decision-maker to choose an alternative: the most suitable or the worst one facing to a particular problem. A decision is a choice made among available alternatives. Group decision-making describes the process where a group of people identify the alternatives and collectively choose a course of action. Marakas[Marakas2003] defines the group decision making as a collaborative activity that involves two or more people.

Literature on group decision-making explores two different aspects of the topic: one is understanding the rules that underlie the process; another consists in engineering systems for assisting people making optimal decisions.

Scott Morton [Morton1971] was a pioneer who tries to implement, define and research test of a model-based decision support system (DSS). Their research showed that most of the time, decisions are made in an organization after obtaining different expert's point of view. He assigns characteristics to the process of decision making:

1. a research process to discover the goals
2. formulation of precise objectives
3. selection of alternatives to reach the objectives
4. assessment of the outcomes

Later, Keen et Scott-Morton[Keen+1978] showed that the more complex organizations are the less individual decisions are made. They stress that the time is a crucial element in the process of decision.

Actually, the group decision making focuses on processes that involve multi-participants who could have divergent interests but who take part more or less in the final decision. The process embed two main steps: the discussion and the decision. The dialogue and mediation steps consist in discussing of the different possibilities to identify the final solution. In this process, the group can discuss of the alternative whereas only one people is in charge to make the ultimate decision.

Research dedicated to better understand group decision-making is mainly focused on the role of argumentation[Brehmer1992], the role of the trust, the role of persuasiveness and the role of reasoning. In this report, we focus mainly on the role of argumentation and the role of reasoning during the decision-making process. The decision making system, we described in our works, intends to support the team to express their opinion arguing with pieces of information. It also intends to put a leader in situation where they must arbitrate and make the final decision.

7.1.2 A conflict to provoke a decision making

The challenge consists in gathering conditions that generate a debate, make team communicate and encourage the leader to decide the best issue. In this context, the decision making model is not designed to support the group in making a decision or emerging issues or alternatives but it is designed to help people express their opinion and support it with coherent arguments.

The first point is to create a context that is likely to make a debate appear focusing on a conflictual problem to solve. The implicit rules of a group decision-making is composed of different elements:

- Identify a topic
- Identify the one who is responsible of the decision
- Identify whom has the best expertise for the discussing topic
- Identify the participants among the teammates
- Identify and rank the different alternatives issues and their consequences

A conflict creates an opportunity for a group to make a decision and beyond this point, it should bring a large team benefit when the conflict is properly managed and detriments on the other case. Indeed, the team conflicts is one of the top concerns of team management [Thompson2013]. They have to be properly managed to avoid hostility and nonperformance and to convert conflict into opportunity to foster solution which reflects different point of views.

Thomson [Thompson2013] compares the conflicts with the cholesterol and classify the conflicts in two categories: a good kind of conflict and a bad kind of conflict. The good kind of conflict offers the opportunity to debate, challenge questions and research the truth or the best solution. They characterize the high-performance teams. On the opposite, bad conflicts concentrate character assassination, denial, angry words... As far as possible, people or colleagues try to avoid the bad kind of conflict and most teams fear that a bad kind of conflicts arises.

Jehn [Jehn1995] classifies the conflicts in 3 types: relationship conflict, task conflict and process conflict.

Basing our toughs on intellective tasks, the deciding issues is neither good or wrong. It depends on the context and particularly on information acknowledged by the leader when they took the final decision. From a disagreement could raise a conflict and from incoherence could born a discussion about what to do to manage this situation.

Table 7.1 – Different kind of conflicts

Type of conflict	Definition	Example of items used to assess the kind of conflict
Relationship conflict	involves disagreements based on personal and social issues that are not related to work	How often do people get angry while working in your team? How much relationship tension is there in your team?
Task conflict	involves disagreements about the work that is being done in group	To what extent are there differences opinion in your team? How much conflict is there about the work you do in your team? How often do people in your team disagree about opinions regarding the work to be done?
Process conflict	centers on task strategy and delegation of duties and resources	How often do members of your team about who should do that? How frequently do members of your team disagree about the way to complete a team task? How much disagreement about the delegation of tasks exists within your team?

In a relationship conflict, the root-causes are often interpersonal friction, ego, tension and personality clashes or communication default. Relational conflict depends on affective and emotional nature of team's member. Task conflict is on the opposite depersonalized. It involves stimulating the teams by confronting ideas, plans and project with differing opinions. Facing to divergent opinion, the team's members are forced to propose an argumentation to support their opinion. Process conflict is centered on disagreements about how to achieve a task and who should do what.

Many studies showed that the the conflicts based on tasks are generally positive effects comparing to those based on relationship that have negative effects[Simons+2000].

In the frame of collective activity, when participants are in conflict, the question of the confidence plays a role. Many studies focused on the task itself and others on the relationship between teammates. Quoting Simons et Peterson[Simons+2000]: "Task conflict, or cognitive conflict, is a perception of disagreements among group members about the content of their decisions and involves differences in viewpoints, ideas, and opinions. Relationship conflict, or emotional conflict, is a perception of interpersonal incompatibility and typically includes tension, annoyance, and animosity among group members".

Jehn [Jehn+2001] established a correlation between the conflicts and the performance. Task conflict bring the most benefits to the team whereas relationship conflicts threaten team performance and team satisfaction which are the main components of team productivity [Jehn1995]. Jehn [Jehn1997] who analyzed conflicts in six organizational work teams notes that on one hand, a task conflict is associated with higher decision making quality, greater understanding, higher commitment and more acceptance. On the other hand, decision making quality, level of understanding, commitment and acceptance decrease in case of a relationship conflict. Facing to divergent point of views, the participant are compelled to consider the opinions of the others and are forced to analyze their arguments.

In the context of a professional activity, professional are involved for a collaborative task based on a tacit agreement to cooperate that limits relational conflicts. In this thesis, we will try to provide tools to help teams to express and make formal task conflicts and process conflicts. Actually, these kinds of conflicts may bring benefits on teamwork effectiveness.

7.1.3 The role of reasoning in a decision-making

Reasoning is used to argue and find arguments, evaluate the relevance of the possible issues facing to a situation [Mercier2009](Mercier, Sperber 2000, 2001). Simon[Simon1965] who studied the role of reasoning in the decision-making process(particularly organization and rationalization) distinguishes five types of decision:

- the objectively rational decision: the decision is the result of a behavior aiming to maximize values of data in a particular situation
- the subjectively rational decision: the decision maximizes the chances to reach a given issue according to the real knowledge of the individual,
- the consciously rational decision: the decision is the result of the mental process of adaptation between means and purposes,
- the rational decision from the organization point of view: the decision serves the organization's goals,
- the personal rational decision: the decision serves the intention of the individual.

The rational decision-making process is composed of four stages:

1. identify the problem/opportunity,
2. think about alternative issues
3. evaluate all the alternative and select a solution
4. implement and evaluate the decision made.

This thesis will focus particularly on the manager's decision making according to argumentation provided by team's members. It will not focus on the participant's reasoning.

7.1.4 The role of argumentation in a group decision-making

Research dedicated to better understand group decision-making focuses mainly on the role of argumentation[Brehmer1992]. Originally, research on decision-making aimed to better understand the rules behind collective argumentation[Sacks+1974] and collaborative decision.

The human capacity to support or defend an opinion with argumentation composes a large part of the human intelligence. Researchers in artificial intelligence and logic programming tried to analyze and mimic the human argumentation to support decision. Dung who is the father of the argumentation systems [Dung1995] proposes to represent the argumentation during a debate between n-persons with a logical system. The argumentation system is represented as an oriented graph where node represent arguments and arcs represent the attack relationship. He uses mathematical logic to represent a conflict, its probable issues and the arguments which defend or attack the possible issues. This argumentation system represents arguments and interaction between them by a n attack-relation.

Definition: Attack graph An attack graph is a tuple $\mathscr{A} = A, \rightarrow$ where A is a finite non-empty set of arguments
$\rightarrow$ is a binary relation - the attack relation.
The set of all attack graphs on a given A is denoted $\mathscr{U}(A)$
the binary relation $a \rightarrow b$ where a,b $\in A$ indicates that a attacks b
$X \rightarrow$ a indicates that $\exists$ b $\in$ X s. t. $b \rightarrow a$

Example:
The attack graph is defined as $\mathscr{A} =< A, \mathscr{R} >$
A is a set of arguments for example $\mathscr{A}$ = a,b,c,d where a,b,c and d are atomic arguments and $\mathscr{R}$ is a set of attack relationship between the arguments.

To illustrate the attack relationship between the arguments (a,b,c,d),
R could be composed of two attacks
R=(a,c),(b,d),(a,d) that means (a attacks c, b attacks d, a attacks d).

Dung defines the notion of acceptability of arguments. These semantics allow to calculate new set of arguments as acceptable arguments.

Acceptability A set of arguments is out of conflict if there is none attack against their arguments i.e. $\forall$ a,b $\in$ A, (a,b) $\notin \mathscr{R}$

Frameworks for formalizing argumentation help to explore possible issues, handle arguments automatically and intend to help to solve complex problems. These model of non-monotonic reasoning are based on three steps: (1) argumentation framework generation, (2) evaluation of arguments and (3) extraction of conclusions. Four approaches intend to structure argumentation: ABA, ASPIC+, Defeasible Logic Programming (DeLP), and deductive argumentation [Besnard+2014]. These systems are either logic-based argumentation frameworks or value-based argumentation frameworks where levels of uncertainty are taken into account [BenchCapon2002].

Besnard et Hunter[Besnard+2008] propose to classify information involved in argumentation. The information (both certain and uncertain information) can be classified in 3categories:

- objective information : information from 'reliable source' that can be observed, measured or checked
- subjective information: information as beliefs or opinion
- hypothetical information: a speculative information that could never be true neither now nor in the future.

Grossi et al. [Grossi+2013] provide using Dung's Theory an analysis of games where players aim at persuading an audience witnessing the argument (abstract argument games). The presence of an audience introduces a specific type of uncertainty which influences the strategic choices of arguments.

According the ‘Persuasive Argument Theory’ introduced by Vinokur [Vinokur1971], the changing views of individuals during a group debate result from argumentation used by the participants. Many experiments showed a strong correlation between the presence of relevant arguments and the changing view in a group. Thus, the role of the argumentation is crucial in a group debate. The polarization is the fact that people in a group join the same opinion. Actually, the polarization phenomena symbolizes the fact that the group tend to make decisions which are more extreme than the initial opinion of their members. Arguments are responsible of polarization or depolarization effect. It depends if they support the initial opinion or if they are opposite. Vinokur et Burnstein [Vinokur+1978] showed that when the arguments in favor and the arguments against an opinion are approximately equally represented and with approximately the same weight, the group’s opinion move to a central point of view and not to an extreme point of view. When the participants debate, all the arguments are in competition but the relevance of an argument has a minor role comparing to the force of persuasiveness. Isenberg [Isenberg1986] made a review of literature between 1974 and 1982 on group polarization. He notes that social comparison and persuasive argumentation processes occur in combination to produce polarization.

Argumentation is based on the known element of information, belief and the situation awareness that is the result of what is known and what is understood. Among all the piece of information acknowledged, only a little part concerns the topic of the decision and among them, only few are relevant to influence the final decision.

7.2 Decision support system

Since 1960’s, researchers studied how computers and analytical models could assist managers to make a key decision.

Research relative to decision making encloses at least two main axes. The first one consists in helping people making decision by simulating and representing different possible alternatives. Artificial intelligence techniques and expert systems have been used to provide smarter support for the decision-maker that includes management systems and knowledge-based decision support systems [Bonczek+1981] [Courtney+1993]. The second one consists in developing software, designing devices or workspace which intend to help group member and decision maker to make the most suitable decision. Decision Support Systems (DSS) are a class of computerized information systems that intend to support decision-making activities and help managers. The systems are interactive computer-based systems and use communications technologies, data, documents, knowledge and/or models to successfully complete decision process tasks. Different kind of digital tools intend to support collaborative work, group decision making as interactive table, a monitoring system composed of public displays and semi-public interfaces to facilitate coordination and team situation awareness.

Steven Alter [Alter+1980] who made a pioneer research on Decision Support System in 1980’s defines three major characteristics of a decision support system:

1. DSS are designed specifically to facilitate decision processes,
2. DSS should support rather than automate decision making,
3. DSS should be able to respond quickly to the changing needs of decision makers.

Collaborative Decision Support Systems is defined as an interactive computer-based systems designed to help to solve ill-structured problems by a set of decision makers working as a team [Kraemer+1988].

The research in Computer Science concerning the decision making embeds various fields as Decision Support System (DSS), Group Decision Support System (GDSS) or just Group Support System (GSS), multiple criteria decision analysis, measurement techniques. . . Decision Support System research aims to study and design system and models to represent mechanisms that are implied in the decision making process when the decision-maker is alone facing a complex situation and when the decision-maker discusses/interacts with others before making their choice: Group Decision Support System (GDSS). In the second case, the manager needs to represent and evaluate the possibilities and the opinion of different people. The choice can be made among two different possibilities or a large number of possibilities. The number of possibilities depend on the state of uncertainty, the level of information of each participant, their beliefs, the quality of the acknowledged information (complete/incomplete, consistent/inconsistent...), the situation awareness. These criteria help to define systems which are based on rational principles and not on probabilist approach.

In the industry, the group decision-making process can be separated in three steps: the brainstorming to generate ideas, the choice and the reporting. Group management and scheduling management are two significant points that impact the efficiency of the decision-making process.

The technological tools which expect to support knowledge and information management tend to answer to three goals:

- help to build a common representation of the activity
- store the reason why the decision was made
- assist the abstraction task

Since few years, thanks to all technological advances, models and communication technology, new systems appeared as group decision support system (GDSS). A GDSS is an hybrid decision support system that stresses both the use of digital communication technologies and decision making models. A Group Decision Support System is an interactive computer-based system intended to facilitate and help decision-makers working together to solve problems.

The group decision support systems used to be associated with a human facilitator. The "faciliator" helps the team members in the process inviting them to debate on a subject for example. Clawson et Bostrom[Clawson+1993] and Nunamaker[Nunamaker Jr+1996] identified functions and roles of facilitator such as prepare meeting, coordinate meeting, create a positive atmosphere during the meeting, learn technology and abilities, promote responsibility, manage conflicts, present information to the group, register comments and results of debates. . . . As a result, they do not participate to the decision making process but they help them to use and share pieces of information during the meeting. On the contrary, the "participants" have a common task to work on, they exchange on the contents. Finally, during a meeting, two categories of role are identified : "the facilitator" and the "participants".

Adla et al. [Adla2010][Adla+2007], for example, propose a distributed and synchronous system that facilitates the group decision making process basing their contribution on the facilitation concept. Their tool presents a set of tasks to realize and associated methods to achieve them. They designed features to enable users to:

1. select a task
2. generate and organize alternatives
3. choose an issue
4. select a method to achieve a task
5. assign tasks to an agent (in a cooperative way)

6. execute the method
7. assess the level of achievement

Their system is composed of associated tools such as a ranking tool (to range the alternative issues), a valuating tool (to estimate on a scale from 1 to 10the relevance of the issue), a selection tool to express a Boolean opinion on an issue 'yes' or 'no'... Their model is based on 3 stages: pre-meeting, decision (during meeting) and reporting (post-meeting stage).

More recent research proposes to help teams using multi-surface environment for communication and collaboration. Chokshi et al. [Chokshi+2014] propose such a system for emergency operation center. They intend to facilitate information and communication exchange in an emergency response planning scenario.

7.3 Decision making in a virtual environment

The past thirty years have seen increasingly rapid advances in the field of Computer Science. Since early 80's, researchers were interested in simulating with computerized simulation financial and economic models.

As an illustration, in 1987, Sterman [Sterman1989] uses a high fidelity macroeconomic computerized simulation to experiment the managers' decision making process. Basing the simulation on investment accelerator model, the computer displays colored graphics and animation to highlight the flows of orders,production, and shipments to increase the transparency of the structure. The operator (only one people) plays the role of a firm manager and has to maintain sufficient capital stocks to answer to the demand. Decision's topics focus on the orders of the capital sectors. The simulator calculates in real-time production, desired production and capacity. Sterman shows that it is possible to experiment the decision rules of a corporate and economic models. But he highlights the interest to experiment the concept with a multi-player simulation and more complex rules.

During the group decision making process, each participants needs to be aware of the current situation to participate to the synchronous and collaborative discussion. It stresses the importance to provide graphical features that help the group both to exchange information and express their opinion to evaluate consequences of different alternatives. Subsequent research aimed to propose models for assisting decision making in various disciplines or more recently to train people to make decision and understand the consequence of their choices, notably using multi-surface learning environment, virtual learning environment and serious games.

As an illustration, this is the case of an American teacher [Burenheide2007] who uses war-games in a real university park as a battlefield to make students aware of the difficulty for an historian to identify real historical events. The historian job consists in identifying historical events between memories of war written by people who lived the war, discourses produced from received letters from soldiers on the battlefield and memories of people who were not locally present. The teacher divides the students in two groups. The groups have to fight on the battlefield. Both the two groups are armed with water-balloons and they play to reproduce an historical battle.

In the educational area, teaching decision-making as a skill has resorted to games as early as the 19th century where the *Kriegsspiel* (war board game) was used in Germany to teach military strategy and decision-making on the battlefield. Different versions of the "kriegsspiel" were edited to learn military strategy and decision making. Nowadays, various computer-based war-games are used to teach tactics and exercice decision making. American Army is one of the well-known collaborative serious war-game. However, it has not been designed to train military forces but designers intent to recruit future soldiers. In this game, players are military forces. The exercise consists in identifying the best strategy that fits the current military situation. They must coordinate their team to win battles and territories.

Video games have accelerated this trend in safety and defense[Hulst+2012], A-CDM (for Airport Collaborative Decision Making) [Freese+2015], clinical healthcare [Kaczmarczyk+2015] or business management [Hauge+2012].

In [Karacapilidis+2001], Karacapilidis describes The Hermes system: a multi-user web-application available throw a web browser. It is an asynchronous and distributed system. It provides basic argumentation elements as issues, alternatives, positions and constraints Author argue that it augments classical decision making approaches by supporting argumentative discourse among decision makers. The figure 7.1 shows a case of study relative to medical decision making concerning a patient's treatment. Three doctors were involved to map the possible alternatives and the argumentation into a hierarchical structure. On this map, each entry corresponds to an argumentation element. The top-level entry corresponds to an alternative and the colored icon (blue/red) symbolizes the argument pro and cons. Hermes integrates features that enable the group to express their reasoning, their opinion and their doubts. An Argument Builder Tool aims at assisting users building robust argumentation but in case of conflict, the system recommends solutions but leaves the final enforcement of decisions to the decision makers involved.

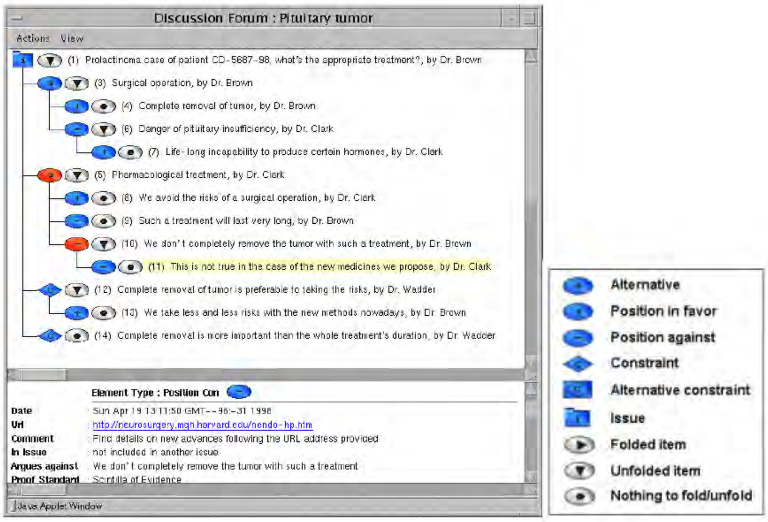


Figure 7.1 – Hermes: distributed and asynchronous multi-user web-application that supports argumentative discourse among decision makers

In most recent research, Daylamani-Zad et al. [DaylamaniZad+2016] propose an add-on architecture (named Lu-Lu) that aims to support collaboration in decision making games using FaceBook's games plateform. Each player has a "decisiveness Index" which shows how effective a player's decision would be informing the team decision. This index is calculated using the player's score, level... The more the player is powerful, the more the important is their "decisiveness index". The leader is automatically selected in a team by the game according to their highest combination of level and score. The leader is the one in the team to be able to send message and advise their team on the game strategy. All other players are notified of the leader's decision. The Lu-Lu architecture has been experiment on a beer multi-player game. The team decision is automatically calculated from individual decision using an adaptation of weighted majority social choice function.

This kind of environment allows to control manipulation of decision context and help to study the dynamic of the decision making process. Serious games are particularly suited for such an undertaking as they enable a player or a group of players to make decisions freely and experience their consequences in a virtual, safe and controlled environment.

An illustration of serious board game is FOWIS [Hertzog+2014]. In this RPG game, eight players take different role. The available role are : (1) family farmer who own irrigable land blocks, (2) large scale investor and (3) a manager of the irrigation scheme in Africa. This board game focuses on management of water using cards and tokens and provide scenarios which represent different contexts (dry and wet season for example). Hertzog et al. analyze manually each game session and key features were manually monitored to know if the stakeholders define a suitable strategy for water management, if they increase their awareness of each others' position and strategies…

Another interesting virtual environment designed to be used in a learning context is "CONNECT"[Baker+1999][Baker2003]. It is a Computer-Supported Collaborative Learning environment for the Confrontation, Negotiation, and Construction of Text) (see fig. 7.2). It was designed to understand the relations between argumentation, interaction and collaborative problem solving. The case of study focuses on interpreting a sound phenomenon in physics. CONNECT enables pairs of students to critically reflect upon and to collaboratively write texts across the Internet. The students must interpret a simple situation in terms of a molecular model of air. Documentation shows an experiment with two tambourines suspended from a support and a small ball being suspended too. Pair of students are involved in a collaborative writing of interpretations of sound propagation. They need to discuss on the different perspectives on sound propagation and agree on a common text. Baker et al. explore the space of combinations of conditions for a specific class of tasks and to study the interactions of students working in such conditions.

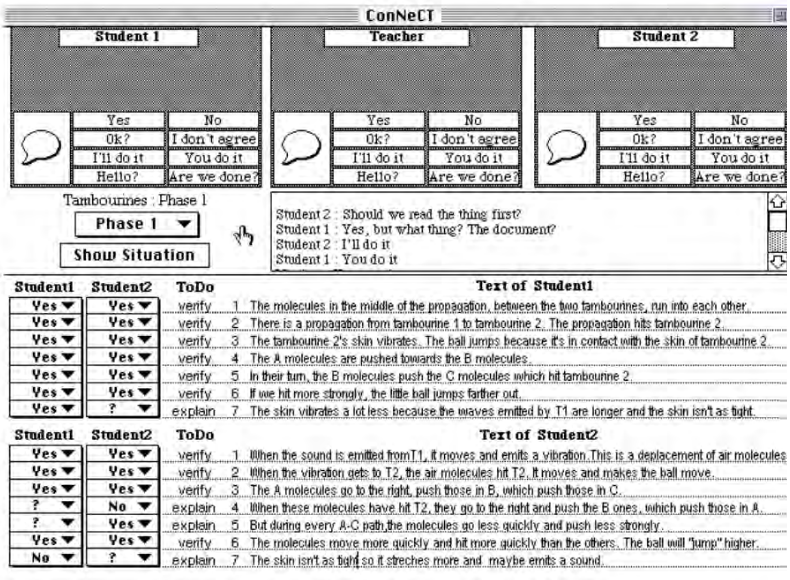


Figure 7.2 – CONNECT: Medium and communication with/in a virtual world

The communication interface is a combination of a dedicated button interface and a chat box free text interface. They restricted communication using pre-defined buttons to communicative acts. Available buttons are: "Yes", "No", "OK?", "I don't agree", "I'll do it", "You do it", "Hello?", and "Are we done?" Clicking on a button makes its label appear in the dialogue history. Clicking on the balloon makes the chat box for typing a message appear.

The task interface displays the individual texts segmented into semantically distinct statements. Students are asked to mark their opinions with respect to each sentence of their own and their partner's text using the menu buttons : "Yes", "I agree"; "No", "I don't agree"; or "?", "I don't understand" or "I don't have an opinion".

These features help the dyad to mimic the decision making process on a collaborative writing but it does not intend neither to help them to interpret the sound propagation experiment nor to show them the incoherence or the consequence of their interpretation.

Recent research relative to "computer supporting learning" propose to use Multi-Surface Environments to support collaborative decision-making and team situation awareness activities [Dillenbourg+2011][Rogers+2004]. Former studies have stressed that using tabletops in collaborative learning activities promotes higher level of reflexion and more effective work [Kharrufa+2010][Higgins+2012]. Multi-surface environments (MSE) appear particularly well suited for such learning activities. Tong et al. [Tong+2017] have developed an application (called Pickit) supporting decision-making process for multi-surface environment. Their application uses both a tabletop and tablets. The tabletop is dedicated to the decision-making context whereas the tablets are dedicated to the data browsing that can support the decision making process (see Fig. 7.3). They decide to follow the analytical process of the decision-making activity, which involves four broad categories of decision-making behaviors: exploring, discussing, awareness and regulation. They demonstrate that their system helps students develop their own ideas and make reasonable decisions providing justifications to support them. The educational scenario focuses on the selection of the best location to establish an insect farm. Students must analyze the geographical and abiotic data of four available locations and choose a location for their insect farm.

Figure 7.3 – PICKIT: multi-surface environment for learning that support decision-making process [Tong+2017]

Although the topic seems to be similar with our context, it presents significant differences. Players/Students have the same level of expertise on the same field whereas in a socio-technical system, the players/students have an expertise in different but complementary fields. Furthermore, the context seems to be static whereas in a socio-technical system, the context is dynamic and evolves while time passes and the shared activity progresses.

WISE (Web-based Inquiry Science Environment) is an online learning platform that includes workshops, interaction with mentors and online supports. It is designed to support teacher interact with their students concerning scientific problem solving [Linn+2004]. Argue-WISE is part of the WISE. It is composed of both knowledge representation and discussion based tools (see figure 7.4). Students use a tool (called SensMaker) to classify evidences they collect into category boxes. They are free to create as many category boxes as necessary. They could also write notes in Evidences pages. Linn et al. [Linn+2004] argue that the design of such a technology-enhanced environment provides scaffolds for argument building, by making reasoning visible. It stresses the reasoning making the structure of argument construction explicit, and structuring both peer to peer and group discussion. Contrary to Linn, Evagorou et al. [Evagorou+2012] suggest that the SenseMaker tool does not support students in collecting and using all available evidence to support their argumentation, since they ignore evidence that contradicted their decision. However, it is important to note that even if the final decision is made discussing naturally in pair or group, this tool intends to support individual argumentation building before a debate project. It provides features that help to organize and range pieces of information found on the platform.

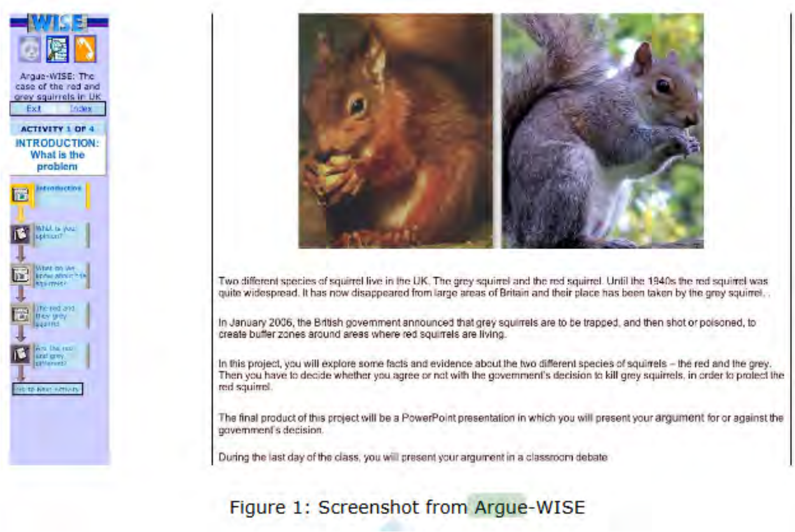


Figure 7.4 – Argue-Wise: knowledge representation to scaffold and structure argumentation relative to a socioscientific problem

V3S is an another example of training environment and decision making tool modeling safety interventions on SEVESO sites[Edward+2008].

7.4 Synthesis

In this chapter, we have presented firstly the definitions relative to decision making and the theoretical concept of group decision process. It is important to note that a conflict almost provoke a debate that starts group decision making process. In our research, the conflict presented to the team would concern only intellective task. Basing our toughs on intellective tasks, the deciding issues is neither good or wrong. It depends on the context and particularly on information acknowledged by the leader when they took the final decision. From a disagreement could raise a conflict and from incoherence could born a discussion about what to do to manage this situation. We stress the importance of memorizing, reasoning and arguing in the decision making process. Secondly, we present different decision support systems designed to facilitate decision process. They should support rather than automate decision making, help to build a common representation of the situation, store the reason why the decision was made. Thirdly, we have presented several virtual environments dedicated to train group on business, educational or entertainment purpose. They provide features that help to build an opinion reasoning on contextual information. Some of them offer features dedicated to support decision making process. The table 7.5 synthesizes the characteristics provided in different contexts.

It is important to note that most of the studied environments propose features to build a personal opinion on a subject collecting pieces of information that could be turn to evidence during a debate. However most of time, participants debate verbally using the digital environment as a support to structure their discourse for example. On one hand, the freedom to have verbal debate can be considered as an huge benefit to express clearly their opinion and argue. On the other hand, it entails the disadvantage to force the trainer to analyze the reasoning or the argumentation of each participant during the decision making process. This analyze cannot be realized in-real time by the trainer.

The present research proposes to embed in a virtual collaborative environment a decision-making system that enables people to express their opinion, argue and make (suitable or non-suitable) decision. This system intents to show to the team the consequences and performance of their choice. Even if there is no real impact in a virtual world, they can easily imagine what could have been the consequences in a real-life situation. Secondly, it aims to train leadership of the manager and future manager, to help them identifying relevant arguments that support teammates' opinion. Thirdly, the environment intends to automatically offer at the end of a game session a personalized analyze of the current session. This analysis should be available both for the students and their trainer. This thesis will focus particularly on the manager's decision making according to argumentation provided by team's members. It will not focus on the participant's reasoning.

Although GDSS used to embed communication features to facilitate meeting scheduling and group decision making process, they need to be support by a facilitator to help them to express the salient problem and coordinate debates. In the current thesis, the training collaborative environment intends to provide both a problem (embed in an educational scenario), communication features and decision making features which will allow team members to express their opinion and argue with objective information. The role of facilitator does not match even partially with the role of the teacher. These features should help an identified virtual manager to make the most suitable decision if their reasoning is correct according to their own representation of the living situation. In our case, there is no personified facilitator.

					Environment features that support Decison making process											
Systems	Support	Application context	Identified leader	Support to collect pieces of information	Feature to memorize pieces of information collected	Feature to organize pieces of information to elaborate evidence/opinion	Sharing piece of information feature	Feature to trigger a debate	Feature to propose or list alternatives/options	Feature to evaluate options	Feature to express Individual Opinion	Feature to vote for an option	Feature to argue an opinion	Making a final collaborative decision feature	Feature to inform the group of the enforced final decision.	Feature to experimenting the consequence of the final decision
Pickit (Tong et al 2017)	Multi-surface environment (tabletop + tablets)		No	the digital environment itsef provides documentation	Yes (writing comments)	Yes(writing argumentation)	No (verbal communication)	No (verbal communication)	No(possible issues are already given)	Yes (positionning stars)	Yes	No	Yes (writing comments)	No (verbal discussion)	No	No
Argue-Wise (Evagorou, 2012)	Computer	Socioscientific problem solving (squirrel)	No	the digital environment itsef provides documentation	Yes	Yes (create a free tree-like structure to organize evidence)	No	No	No	Yes	Yes	No	Yes	No	No	No
Connect (Baker, 1999)	computer	physics phenomena (sound propagation)	No	No (paper documents)	No	No	Yes (text-chat)	Yes (Text-chat)	Yes(text-chat)	No	Yes	Yes	Yes(text-chat)	No	No	No
(Daylamani et al, 2016)	social network game	supply chain beer game	Yes	the environment itsef provides pieces of information	No	No	No	No	No	No	Yes	No	No	Yes	Yes	Yes
Fowis (Hertzog, 2014)	board game	water management	No	Token and cards (tangible paper documentation)	No (writing comments on papers)	No (writing or naturally spoken)	No (verbal communication)	No (verbal communication)	No (verbal communication)	No (verbal communication)	No (verbal communication)	No (verbal communication)	No (verbal communication)	No (verbal communication)	No (verbal communication)	
Hermes (karacapilidis	computer	medical (patient's treatment)	No		No		Yes	No	Yes	Yes	Yes	No	Yes	No	No	No

Figure 7.5 – Synthesis: Comparative analysis of features provided in group decision making environment

Chapter

8

The grail of traceability

The next sections present some examples found in field of artificial intelligence or learning analytics that intend to provide systems able to monitor activity and/or present results from analyzing the data collected throw the virtual environment.

8.1 Intelligent Tutoring Systems

From the education field and the artificial intelligence field was born the Intelligent Tutoring Systems (ITS). Conati synthesizes the objectives of intelligent computer-based tutoring: support for collaborative learning [Isotani+2008], emotionally intelligent tutors [Conati+2009] [Dmello+2008], teachable agents who can help students acting as peers [Leelawong+2008], intelligent support for learning from educational games [Manske+2005] [Johnson2007] and intelligent tutoring for ill-defined domains [Lynch+2008].

Originally, tutoring systems focused primarily on tracing students' knowledge state. Later, ITS have focused on a probabilist approach that consists to estimate the probability that the learner is close to do something wrong or is disengaged or is "gaming" the tutoring system [Beck2005] [Aleven+2009]. To that end, they use time traces of student actions with the ITS.

As an illustration, Conati et al. [Conati2002] propose a probabilistic model to monitor a user's emotions and engagement during the interaction with educational game.

8.1.1 A probabilist approach : Bayesian Networks

A Bayesian Network is a probabilistic graphical model represented by an oriented and acyclic graph that encodes probabilistic relationship among variables of interest. Each node represent a random variable and the arcs express a dependency, influences between these variables. To quantify the weight of the dependency or influence between variables, a conditional probability is associated to each node.

We begin by reviewing Kolmogorov's approach. Kolmogorov introduces the conditional probability of A given B as the ratio of unconditional probabilities. A conditional probability is the probability of one event (A) if another event (B) occurred. The conditional probability of A given B is the probability notation is: $(P(A|B))$
Bayes theorem is a pillar of both probability and statistics. It enables us to invert conditional probabilities i.e. to find P(A|B) from P(B|A).

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \tag{8.1.1}$$

The event A is independent of the event B if the conditional probability of A $(P(A|B) = P(A))$ In our case, events are most of the time dependents.

The law of total probability is defined as follow:
Events $B_1, ..., B_n$ form a partition of a sample space Ω if
(i) they are mutually exclusive $B_i \bigcap B_j = \emptyset i \neq j and \forall i, j \in (1, ..., n)$ where n $\in \mathbb{N}^*$
and
(ii) their union is the sample space $\Omega : \bigcup_{i=1}^{n} B_i = \Omega$

$$P(A) = P(A|B_1)P(B_1) + ... + P(A|B_n)P(B_n)$$

The probability of A is the weighted average of the conditional probabilities $P(A|B_j)$ with weights $P(B_j)$

The law of total probability allows to use multiplication rules to find probabilities.

If a sample space Ω is divided into n disjoint events $B_1, B_2, \ldots B_n$
where n $\in \mathbb{N}^*$
For any event A

$$P(A) = \sum_{i=1}^{n} P(A \cap B_i) \tag{8.1.2}$$
$$= \sum_{i=1}^{n} P(A|B_i)P(B_i) \tag{8.1.3}$$
$$\tag{8.1.4}$$

Tree structure is a great way to organize computations with conditional probability and the law of total probability. The figure exemplifies with a toy-sample a Bayesian net and tries to make clear what a tree structure means.

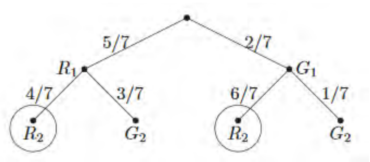


Figure 8.1 – A Bayesian Net sample.

We can interpret the tree as follows. Each dot is called a node. The tree is organized by levels. The top node (root node) is at level 0. The next layer down is level 1 and so on. Each level shows the outcomes at one stage of the game. Level 1 shows the possible outcomes of the first choice. Level 2 shows the possible outcomes of the second choice starting from each node in level 1. Probabilities are written along the branches. The probability of R1 is 5/7. It is written along the branch from the root node to the one labeled R1. At the next level we put in conditional probabilities. The probability along the branch from R1 to R2 is $P(R2|R1) = 4/7$. It represents the probability of going to node R2 given that you are already at R1.

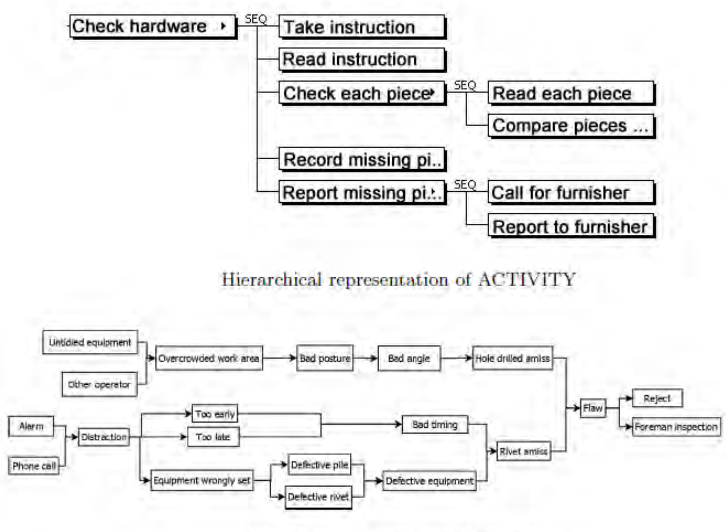
Two methods can be applied to build Bayesian Network while they also can be combined. The first one consists in making experts define the links between the nodes and the conditional probabilities and express their values. The second one consists in collecting a large number of data and instantiating the Bayesian Network from the statistical results.

8.1.2 Examples

HERA

Some researchers intend to develop intelligent tracking system. This is the case of Amokrane et al. [Amokrane+2008]. They develop a learner tracking system that embeds an intelligent tutoring system, called HERA (Helpful agent for safEty leaRning in virtuAl environment).

Hera [Amokrane+2008], has been designed to train professionals on industrial procedures especially those who work in industrial sites with high level of risks. Here, a bayesian network is used to forecast the occurrence of an adverse event given some user's actions have already been already executed. Potential adverse events are represented by nodes (see Fig. 8.2). Their parents' nodes are tasks that have been executed following wrong process. The law of conditional probability is established by experts in the field.



Hierarchical representation of ACTIVITY

Graph representation of CAUSALITY

Figure 8.2 – Humans framework [Carpentier+2013] uses ontology to represent a hierarchical structure of an individual activity. An acyclic graph is used to represent a possible causal chain of events that might lead to an accident

V3S

Another example illustrates the case of a virtual environment designed to be used in a risk management training context. V3S [Barot+2013] is a training environment designed to train professional on industrial risk management particularly for tank truck drivers. The design deals with the pedagogical objectives and the player's profile. Seldon (ScEnario and Learning situations adaptation through Dynamic OrchestratioN) aims to generate and control the scenario within a virtual environment [Carpentier+2013]. This language has been inspired by two task-description languages developed in the ergonomics and Human Computer Interaction communities: MAD (Analytical model for task-description) and GTA (Groupware Task Analysis) [Sebillotte+1994][Van Der Veer+1996]. As a result, the description is based on a cognitive analysis of a task rather than logical analysis of a task. Using this model, a set of possible goals/tasks and subgoals/tasks are described. This description translate the operator's viewpoint of the activity, the relations between the goals and the possible flow of actions and conditions of their achievement. This environment is composed of several modules that communicate with each others. Each one is responsible for specific features as "‘the state of the world"’ manager module, a monitoring module... One of them aims to manage the scenario design. The design deals with the pedagogical objectives and the player's profile. Seldon (ScEnario and Learning situations adaptation through Dynamic OrchestratioN) aims to generate and control scenario within a virtual environment [Carpentier+2013]. All the modules are based on models. One of them aims to manage all the listed risks, their consequences and the way to reduce or avoid them. This model is based on Bayesian Networks that help to determine the frequency of occurrence relative to a risk when a user makes a mistake. Here Bayesian Networks have been used to predict the occurrence of new potential risk calculated on user's activity in the virtual environment. Each risk is represented as a node whom parent is an erroneous task. These models are used to monitor learners' actions and to generate virtual characters' behaviors.

ANDES

Another example is the case of ANDES [Conati+2002] which uses a graph to represent the knowledge and particularly a set of possible issues relative to an exercise. This graph is moved to a Bayesian Network whom relational dependencies represent causal relationship. The main argument that can be advanced to support the Bayesian Net model is that they combine in the same theoretical framework probabilities from statistical processing base on experimental feedback and subjective probabilities. Probabilities in this case should help to assess the student's skills according to their activity during the session.

The main two weaknesses of using Bayesian Network is (1) the difficulty to build and maintain a Bayesian network (2) the difficulty to reasoning on a large number of uncertainty. The underlying argument against is that it would be particularly complex to build a big size Bayesian network: this is the case of a socio-technical system and a teamwork activity (parallel task, community task) including communication and debate.

8.2 Learning Analytics

The field of Learning Analytics is an emerging area that explores the measurement, collection, analysis and reporting of data collected during students' learning through their environment [Brown2011] [Chatti+2012] [Greller+2012]. This field focuses on tracking learning activities and their educational context. Research in this field aims to promote awareness and reflection resulting from algorithmic analysis (in educational data mining or information visualization).

Some research intend to develop a learning analytic dashboard to present student's activity both to learners and teachers b[Govaerts+2012][Park+2015][Verbert+2014].

Verbert et al. [Verbert+2014] propose an overview and compared fifteen dashboard applications. They classify them with the following criteria:

- intended goals and target users
- data-extraction and mining
- visualization
- evaluation

They pointed out that many additional data sources may be relevant indicators to increase awareness and reflection about the learning process.They highlight that dashboards rely mainly on traditional system logs but few systems integrates their own tracking tools in the analytic process.

In the industry of 'serious games' and more widely 'Video games', most of the analytics came from tracing the user-generated data when they interact with the system. In the case of 'Serious Games' and more specifically 'Learning games', the analytics concerns the training/learning assessment [Loh+2015].

Among the metrics, the themes of engagement, motivation, player's profile, player's strategy... are traditionally the core of learning analytics concerning serious games. Bouvier et al. [Bouvier+2013] based their work on engagement and engaged-behaviors, Activity Theory and Trace Theory to identify learners' engagement in learning games from their traces of interaction. "'Identifying engagement inform about learners' motivation, acceptance and attachment to the learning activity"'. User's engaged-behaviour can be consider through some sequences of actions. Beal et al. [Beal+2006] propose a classification approach of learner's engagement. This classification also predicted students' strategies while using the ITS. Bovo [Bovo2014] also characterizes engaged-behaviors by identifying four types of engagement: environmental, social, self and actions.

Lastly, visualizations support designers, researchers, teachers and learners, each one can explore, compare and draw insights from the data sets. The visualizations can be used by learners themselves to monitor their progress, compare their performance to their peers [Govaerts+2012][Duval2011]. New approach such as telemetry is used to compare players' behaviors [Gleicher+2011][Liu+2015] Furthermore, teachers also need tools to monitor and compare their students' performance. They also need visualization tools to help them displaying post-training outcomes [Ritsos+2014].

In this thesis, we intend to develop integrated tools that collect data from users' activity in order to present the results of their analysis in real-time immediately at the end of a game session. It may help teachers to lead a personalized debriefing immediately after the training session. One of the specificity in our works concerns the importance to graduate the level of completion of a task achievement, the level of risk assessment and the team behavior facing to an education professional-like situation. A team behavior is not entirely right or wrong, some mistakes may be made, defense barriers may not entirely be efficient. It is crucial to assess the system as a whole to understand the chain of events that lead to an accident. To that end, the collected data sets must be analyzed and displayed to visualize the system as a whole.

8.3 Monitoring dialogue

One of the main difficulty to control and monitor the team activity concerns the dialogue between teammates. The pinnacle of traceability in games that use communication features consists in using dialogue trees. In a dialogue tree, every utterance, question or answer is scripted in a tree-like structure (see section 5.3).

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. However, this previously mentioned method suffers from some serious limitations. Even if the player influences the progress of the story, their freedom is most of the time extremely limited. The main reason is linked to the necessary colossal job of designers to write every line of dialogue that will be available during the conversation. 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 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.

One of the main difficulty is to elaborate and monitor communication and group decision making resulting from conversation. User-generated data must be tracked, collected, analyzed and presented in order to promote awareness and reflection resulting from their activities. This implies to entirely control the interactive scenario and monitor information exchanges, decision making and argumentation to point out the possible reasoning errors or wrong decisions.

8.4 Synthesis

Firstly, this chapter presents different uses of Intelligent Tutoring Systems to support learning through some examples of VE designed for training. The pros and cons of a probabilist approach has been highlighted to understand how Bayesian Networks can be used in the case of training and more widely in the case of risk management training. Even if Bayesian Networks can be an opportunity to predict the occurrence of events that may increase a risk, they suffer from weaknesses such as the the difficulty to build and maintain a Bayesian network and the difficulty to reasoning on a large number of uncertainty.

Secondly, this chapter presents a through some examples recent research concerning games and Learning Analytics. It pays a particular attention on dashboards that present the results of analysis from tracking users' activities in VE. Our work does not focus neither on indicators such as time spent by learners on activities nor on engaged-behaviors. It aims to gather effective data that allows us to trace team's strategy and e-built their reasoning in order to detect non-suitable behaviors related to the situation. The point is to be able to identify non-efficient barrier of defense

One of the main difficulty addressed by this thesis is to elaborate and monitor both actions, communication and group decision making. User-generated data must be tracked, collected, analyzed and presented in order to promote awareness and reflection resulting from their activities. This implies to entirely control the interactive scenario and monitor information exchanges, decision making and argumentation to point out the possible reasoning errors or wrong decisions.

In this thesis, we will propose an innovative communication system and a decision-making system embed in the VE that can be monitored in order to automatically present a personalized debriefing based on user-generated data.

Chapter

9

Conclusion

9.1 Conclusion in French

Version française Dans ce chapitre, nous nous sommes attachés, dans un premier temps, à présenter les concepts théoriques relatifs à la communication, la conscience de la situation et à la prise de décision en équipe. La communication joue un rôle crucial dans la conscience de la situation par l'équipe et cela a un impact décisif sur les décisions de groupe en cas de difficulté. Dans ces travaux, le mot "communication" fait référence à l'échange d'information. Concernant la prise de décision, il a été souligné que le processus de prise de décision collective est activé en situation de conflit. Les conflits sur lesquels le groupe devra opérer une décision par la suite feront référence à des tâches intellectives, c'est à dire des tâches dont l'issue correcte reste démontrable et non subjective. Il a ensuite été souligné le caractère essentiel du raisonnement et de l'argumentaire au sein de débats concernant des tâches intellectives.

Dans un deuxième temps, nous avons présenté les caractéristiques d'un environnement virtuel multi-joueurs au travers de la représentation d'avatar, de la mise en scène d'univers interactifs, de la présentation de missions composées de tâches à la fois individuelles et collectives. Parmi les environnement virtuels multi-utilisateurs, figurent les environnements multi-utilisateur permettant de simuler à l'identique un contexte réel dans un objectif d'entrainement collaboratif et les environnements de jeux multi-joueurs conçus pour se divertir tels que les jeux vidéo multi-joueurs accessibles sur console, sur mobile ou sur ordinateur et enfin les environnements virtuels représentant de manière créative la réalité dans le but de servir des intérêts pédagogiques. Des environnements tels que les serious games et en particulier les learning games, même s'ils font l'objet de quelques réticences, offrent de formidables opportunités en matière de formation. En effet, ils peuvent combiner des mécaniques et techniques éprouvées dans l'édition de jeu vidéo tout en offrant une représentation créative de la réalité permettant de servir des enjeux pédagogiques préalablement définis.

Dans un troisième temps, ce chapitre a présenté différents systèmes de communication présents dans les environnements virtuels collaboratifs. La communication peut être abordée au sein d'un environnement virtuel de différentes manières : communication verbale, communication écrite, communication non-verbale (gestes, animation faciale, animation de personnages, déplacement...). Nous nous centrons particulièrement dans la suite de ce travail sur la communication d'informations dites verbales. Les applications utilisées pour communiquer peuvent soit faire partie intégrante de l'environnement soit être complétement dissociées. Parmi celles qui sont dissociées de l'environnement, figurent les solutions liées à la reconnaissance vocale, le text-chat, les chat-rooms, les forums... Elles offrent toutes (hormis la reconnaissance vocale) de formidables fonctionnalités permettant de simuler ou reproduire une discussion tout en donnant une grande liberté d'expression aux utilisateurs. Cependant, les solutions liées à la reconnaissance vocale ne permettent pas à ce jour ni d'assurer une fluidité dans les échanges entre membres d'une même équipe ni même de contrôler de manière fiable les sujets de discussions abordés oralement. Elles s'appuient principalement sur des dictionnaires limités de vocabulaire. Lorsque les environnements virtuels multi-joueurs proposent un système de communication pour aider les joueurs à élaborer ou définir une stratégie, les fonctionnalités suivantes ont été identifiées :

- envoyer un message à l'aide d'une bulle d'information présentée textuellement ou à l'aide d'émoticône
- envoyer un message textuel avec un text-chat libre
- constuire et envoyer un message textuel constitué de mots prédefinis
- envoyer un message verbal sonore
- parler naturellement
- envoyer un message vidéo
- envoyer un message graphique (alerte sur une carte par exemple)

Dans un contexte socio-technique dynamique, il est essentiel de favoriser les systèmes de communication temps-réel pour mettre en place des communications synchrones. Les solutions de text-chat, de chat-room ou de forum de discussions même si elles offrent une grande liberté aux utilisateurs, font l'objet des mêmes critiques. Il reste extrêmement difficile de contrôler en temps réel les sujets de discussions abordées et les informations échangées par les utilisateurs dans ces contextes. Par contre, ces outils utilisent des métaphores graphiques et proposent des fonctionnalités indispensables à la mise en place de dialogue en temps-réel. Les solutions de gestion de la communication intégrées, quant à elles, proposent la plupart du temps des fonctionnalités graphiques pour communiquer au sein de l'environnement. Cependant, dans la plupart des cas, lorsque le dialogue doit s'engager entre deux personnages, les dialogues sont pré écrits sous forme d'arbre de dialogue. Cela présente l'avantage de contrôler à tout instant à la fois les sujets de discussions mais aussi la progression dans les échanges. L'inconvénient majeur de ce procédé est qu'il nécessite de formuler toutes les combinaisons possibles pour décrire les échanges ou bien de restreindre considérablement la liberté d'expression des joueurs à un petit nombre de possibilités. Par conséquent, il est absolument impensable d'écrire manuellement l'ensemble des combinaisons possibles lorsque les échanges portent sur un grand nombre d'informations et mettent en jeu plusieurs personnes. Lorsqu'il s'agit d'échanges avec un agent autonome ou agent conversationnel, les échanges peuvent être gérés à l'aide d'algorithmes d'intelligence artificielle. Dans le monde du jeu vidéo, plusieurs techniques sont utilisées pour permettre l'échange d'informations, mais elles ne sont pas monitorées parce que la communication dans ces contextes de divertissement reste un moyen pour parvenir à un but. La communication ne constitue pas un objectif en-soi.

Dans un quatrième temps, nous avons présenté des univers dans lesquels les utilisateurs avaient pour mission de prendre des décisions. Certaines applications sont developpés dans le but d'aider à la prise de décisions en simulant différentes solutions possibles et en proposant des projections de conséquences probables des choix envisageables. Dans nos travaux, nous

nous interessons plus particulièrement aux solutions permettant à un groupe d'échanger des informations pour se construire une meilleure représentation de la situation réelle et ainsi être à même de choisir l'alternative la mieux adaptée. Parmi les environnements permettant l'échange d'information au sein d'une équipe en vue d'une prise de décision, la majorité sont des environnements hybrides qui offrent une vue agrégeant des informations issues d'applicatifs différents, des dispositifs multi-surfaces composés d'applicatiions utilisant tablettes tactiles et table interactive pour permettre à la fois de collecter des informations, de les agréger de manière à donner une représentation la plus juste possible de la situation en cours, de les mettre à disposition du groupe afin que les débats soient lancés et les décisions puissent être prises. Ces dispositifs permettent effectivement de rassembler les informations pour avoir une représentation synthétique de la situation courante, de proposer et d'évaluer les alternatives possibles et de prendre une décision. Cependant, les débats précédents la prise de décision, les opinions et l'argumentaire figurent très rarement parmi les fonctionnalités proposées au sein de tels environnements. Les étapes d'échanges s'opérent généralement oralement et ne peuvent donc pas être débriefer automatiquement a posteriori.

9.2 Conclusion in English

Firstly, the main characteristics of a collaborative virtual environment have been described such as avatar's representation, interactive universe, mission briefing… Among all virtual interactive and collaborative environments, some are designed to simulate with high fidelity a professional context for training purpose. Others have been designed for learning purpose and represent with certain creativity the real context in order to serve educational objectives. Virtual environments like serious games and particularly learning games, even if they are criticized, offer great opportunity in terms of training and learning. As a proof of that, learning games can combine both game design mechanisms and interaction validated in video-game industry and creative representation of reality that supports predefined educational objectives.

Secondly, in this chapter, we have presented the definitions relative to communication and the theoretical concept of team situation awareness. It is important to highlight the importance of communication to build the most realistic as possible representation of the dynamic situation. In our research, communication refers to information exchanges. 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 modeling… Even though, the field of communication is very large, we mainly focus on verbal communication excluding facial animation, gesture, emotion, movement and body animation.

We have presented through different examples digital and virtual contexts where communication between two people is part of available features to achieve a mission. However these contexts can be extremely different: environments where a human communicate to another human, environment where a human and a character controlled by a computer (CCC) have to communicate either in a cooperation relationship to achieve a common goal or in a competition relationship.

The models 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. Different possibilities to simulate a verbal conversation between two humans exist:

- a human participant talks to another human participant by text chat, by voice chat or naturally speaking
- a human participant talks to a computer and the computer transmits to another human participant

- a human participant sends predefined information to another human

Communication systems used to support cooperation can be divided into two groups: those which are completely integrated to the software and those which are dissociated. Speech recognition, text-chat, voice-chat, web forum, chat-room are some examples of issues that can help to support information exchange. Except voice recognition technique (speech-to-text and text-to-speech techniques), they offer great features to mimic a dialogue leaving complete freedom to choose a conversation topic or information to exchange. However voice recognition can not assure fluidity of information flow in a conversation between three persons at least. Moreover, these techniques seem to be uncompetitive with a large dictionary. When virtual environment provides a communication system that supports communication between users, some features have been identified such as:

- send a message with an information bubble (text or icons like emoticons)
- send text-message with a free text-chat
- build a text-message with predefined words
- speak naturally
- send a video-message
- send a graphical or sound message (set a flashing element on a map, ping a map for example or send a sound alert)

The table 6.7) synthesizes the different communication channels provided to users in different contexts.

In our case, the dynamic context impose to promote real-time communication systems. Even if text-chat, chat-room or forum offer freedom and flexibility, information exchange is extremely complex to be monitored in real-time. It is important to note that most of the studied environments propose communication features that do not enable monitoring information exchange except those that entirely describe communication through dialogue-tree. The main inconvenient using the dialogue-tree relates to the limited number of combinations that can be manually described. The higher the number of participants in a conversation is, the higher the number of possible combinations is. Moreover, the number of combination also depends on the quantity of pieces of information the participants know. As a result, the dialogue tree representation is definitely not a good technique to use to support communication between more than two participants who need to manipulate a large number of information.

Thirdly, fostering and supporting communication in a digital and real-time environment implies respecting some implicit rules.

The communication system described in this thesis proposes features to allow avatar's conversation. It is based on the implicit rules of face-to-face 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)

In the last section, we have presented firstly the definitions relative to decision making and the theoretical concept of group decision process. It is important to note that a conflict almost provokes a debate that starts group decision making process. In our research, the conflict presented to the team would concern only intellective task. Basing our toughs on intellective tasks, the deciding issues are neither good or wrong. It depends on the context and particularly on information acknowledged by the leader when they took the final decision. From a disagreement could raise a conflict and from incoherence could born a discussion about what to do to manage this situation. We stress the importance of memorizing, reasoning and arguing in the decision making process. Secondly, we present different decision support systems designed to facilitate decision process. They should support rather than automate decision making, help to build a common representation of the situation, store the reason why the decision was made. Thirdly, we have presented several virtual environments dedicated to train group on business, educational or entertainment purpose. They provide features that help to build an opinion reasoning on contextual information. Some of them offer features dedicated to support decision making process. The table 7.5 synthesizes the characteristics provided in different contexts.

It is important to note that most of the studied environments propose features to build a personal opinion on a subject collecting pieces of information that could be turn to evidence during a debate. However most of time, participants debate verbally using the digital environment as a support to structure their discourse for example. On one hand, the freedom to have verbal debate can be considered as an huge benefit to express clearly their opinion and argue. On the other hand, it entails the disadvantage to force the trainer to analyze the reasoning or the argumentation of each participant during the decision making process. This analyze cannot be realized in-real time by the trainer.

The present research proposes to embed in a virtual collaborative environment a decision-making system that enables people to express their opinion, argue and make (suitable or non-suitable) decision. This system intents to show to the team the consequences and performance of their choice. Even if there is no real impact in a virtual world, they can easily imagine what could have been the consequences in a real-life situation. Secondly, it aims to train leadership of the manager and future manager, to help them identifying relevant arguments that support teammates' opinion. Thirdly, the environment intends to automatically offer at the end of a game session a personalized analyze of the current session. This analysis should be available both for the students and their trainer. This thesis will focus particularly on the manager's decision making according to argumentation provided by the team members. It will not focus on the participants' reasoning.

Although GDSS used to embed communication features to facilitate meeting scheduling and group decision making process, they need to be supported by a facilitator to help them to express the salient problem and coordinate debates. In the current report, the training collaborative environment intends to provide both a problem (embed in an educational scenario), communication features and decision making features which will allow team members to express their opinion and argue with objective information. The role of facilitator does not match even partially with the role of the teacher. These features should help an identified virtual manager to make the most suitable decision if their reasoning is correct according to their own representation of the living situation. In our case, there is no personified facilitator.

Part III

Contributions

Chapter

10

Designing an educational risk management scenario based on real-life cases

10.1 Classical challenges to design an interactive scenario

In the first part of this report (see section 5), we define an educational interactive scenario as a set of elements :

1. a briefing : presentation of the current situation and expected objectives to reach : the mission

2. the virtual universe: objects, furniture, documents, characters. . .

3. a set of actions, pieces of information, documents, furniture and objects which can be manipulated throw the universe to achieve the mission

4. playful and educational lockers such as educational prerequisites, educational failures to avoid...
5. educational skills to develop or acquire
6. concepts which can be manipulated with interactivity through the environment: game play elements as inventory of assets, monetary system, virtual store... and educational concepts as programming, making decision...
7. steps or levels which compose the mission
8. educational objectives to reach (visible or not in a briefing stage)
9. a debriefing: summary of outcomes with feedback that should help the player to succeed in the future

This definition particularly suggests that interactive storytelling triggers challenging opportunities in providing effective models for enforcing autonomous behaviors for characters in complex virtual environments. In other words, players should be able to be wrong, patch their errors, succeed.

In the case of training environment for high graduated students, the challenge consists in :

1. representing with creativity but also with high fidelity the professional environment through the virtual universe
2. providing opportunities to characters to choose what they want to do
3. providing interactions as part of the professional activity using objects/equipment/furniture/abstract elements arranged in the virtual universe
4. giving relative but controlled freedom to act in the universe in order to compare with the expected behaviors.

Here, the word object will henceforth refer indifferently to furniture, equipment, document, character, patient...

10.2 Specific challenge to foster communication

In socio-technical context, individuals can exchange information, act and cooperate so as dynamic and interdependent way in a scalable environment[Salas+1995].

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 character's 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 below allow users to accomplish individual tasks and to ask their teammates to coordinate themselves to accomplish collaborative tasks.

10.3 Specific challenges relative to risk management training

Training in risk management can be approach by different ways:

1. training for emergency situations
2. improving the ability to identify and understand a critical situation and improve the situation awareness of a critical and risky situation [Frank+2002]
3. providing training technical skills on technical equipment with or without automation [Puentes2011][Gaba+2001]
4. providing maintenance training on dangerous equipment [Gerbaud+2007]
5. training with exceptional/uncommon situations
6. training in a safety environment without any consequences in real life [BinSubaih+2009]
7. training to organize/deploy rescue or intervention forces in case of disaster [Markenson+2005]

Several markets have been addressed to train on emergency situations such as medical emergency [Stytz+1996], military intervention for war prevention [Swartout+2006], bioterrorism preparedness [Markenson+2005], nuclear emergency [Crichton+2004], industrial risks[Edward+2008]...

However, these works fails to consider the human factors such as communication which is listed among the main root causes of accidents. They mainly focus on scheduling or technical skills and their approach is centered on the individual aspects of risk management.

We choose here to design a collaborative virtual environment for training providing library of professional contexts. The library is composed of both exceptional but extremely dangerous situations and typical situations. The first point is to improve the team situation awareness in order to make the most suitable decision according to the current context. The second point is to improve the ability to identify and be aware of a situation especially when it is critical.

In others words, the challenge relates to provide a controlled situation where students are relatively free to act, can influence the progress of the story and can reproduce a causal chain of events that lead to an accident.

10.4 Two categories of educational scenario: perfect initial situation and irregular initial situation

Designing real-life situation for risk management training consists both in (1) representing a perfect initial situation with competitive experts who made zero errors before the team must manage the current situation and (2) representing an irregular situation where experts made mistakes that can lead to an incident if the errors are not tracked and corrected on time. If they are not corrected in time, problems will reveal as being part of the causal chain of events that lead to an adverse event.

The first category of situation called “standardized situation” aims to train teams applying routines and policy safety procedures in regular cases. It is easier to design because it requires to interview experts, to understand, express the business process and model their jobs and their activity when everything is perfect without any disruption.

The other one called “irregular situation” aims to make team understand the interest of applying or adjusting policy safety procedure to avoid accidents. Designing such a situation is more complex because it requires also analyzing the chronology of events before an accident and identify the causal chain of events and their root-causes.

We decide to design these 2 categories of situations. Basing our thoughts on methods to analyze real incidents or accidents in socio-technical systems, we designed “irregular situations” both dispatching failures or errors in an initial perfect situation and providing erroneous available issues during a decision making or inappropriate tasks in the cloud of available tasks.

The next section describes the Reason’s Swiss model to represent a complex socio-technical situation that leaded to an accident. It helps to understand the method we use to design a scenario based on an “irregular situation”.

10.4.1 Draw up an educational scenario basing on a real causal chain of events that leaded to an accident

Extensive researches into disasters such as the nuclear melt down at Chernobyl, the Boeing 747 collision at Tenerife [Weick1990], the explosion of space shuttle Challenger [Vaughan2004] or the disintegration of space shuttle Columbia [Hall2016], typically focus on the chains of events which caused these disasters. When such accidents are more closely analyzed , organizational problems, equipment breakdowns or loss of communication accuracy are often revealed as being part of the causal chain of events.

An accident generally does not result from a single mistake or error but results from multiple causes. Despite the existence of safety barriers, they may happen because error is human. Different methods to analyze accidents and risks after slips happened exists. Some of them are based on systemic-based technique. System-based technique methods are specially used for analyzing the causes of accidents or incidents that occur in socio-technical systems.

Studying complex system, Reason [Reason2013] shows that most of the time, accidents result from multiple successive failures which could not have been corrected or stopped in time. Reason’s model[Reason2000] proposes that within complex systems, multiple barriers or layers exist to prevent accidents or errors. Mostly they do this very effectively, but there are always weaknesses. Among the weaknesses, a poor communication between team members is often identified as an underlying factor of near-misses or accident.

The Reason’s Swiss Cheese Model (see Fig. 10.1) represents the system as a whole. Each slice of cheese represents the organization’s defense against failures and mistakes. The holes in the slices represent individual or collective weakness. The whole system is dynamic and the holes can varies in size and position in the slices as far as the situation evolves. The system can trigger accident when errors or mistakes are temporary aligned because none defense barrier can avoid the accident. As the result, when the holes in all slices are temporary aligned, they allow ’a trajectory of accident opportunity’.

In a complex socio-technical system, committing zero error is most of the time nearly impossible. However, it is possible to build defense barrier to detect mistakes and avoid unpredictable accident. The pursuit of greater safety is hindered by an approach that does

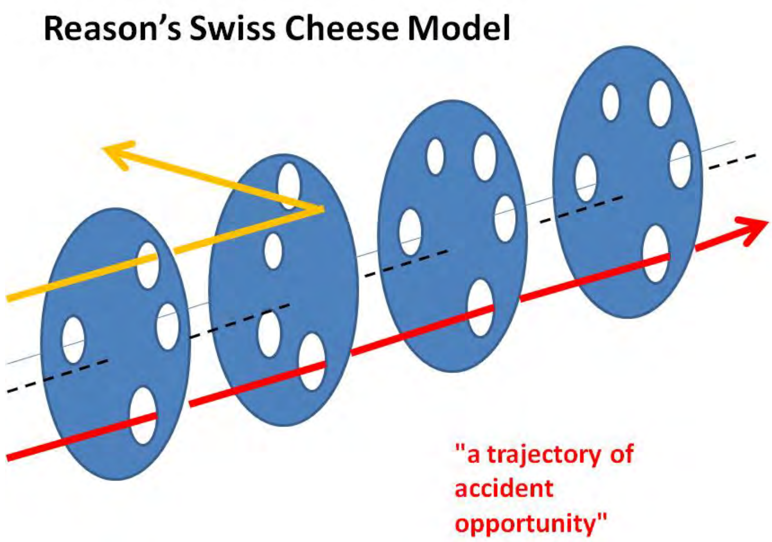


Figure 10.1 – The Swiss Cheese Model - Reason

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.

Rasmussen who originally developed a part of risk management strategy [Rasmussen1997] defines the performance of an activity with three levels: skill-based, rule-based and knowledge-based. Therefore slips and fails can come from rules-based, skills-based or/and knowledge-based levels.

As a consequence, designing educational real-life situation for training consists in dispatching holes in a predefined situation and providing features that make team able to act, track and correct mistakes/failures using defense barriers.

The next section describes methods used to analyze the chain of events that leaded to an accident. It helps to understand the method we use to model educational feedback at the end of a game session.

10.4.2 Systemic analysis methods in healthcare

The two main systemic methods used to study near-misses or adverse events in an healthcare context are ORION method [Debouck+2012] and ALARM (Association of Litigation And Risk Management) method [1999] [Raux+2007]. Vincent [Vincent2004] explains that analysis technique is not only a search for a root cause but "an attempt to look to the future". Methods help to reveal the weakness of the system and help to improve it.

The idea that not only the disease but also the diagnostic and therapeutic approach by invasive examinations or treatment can ultimately be harmful to the patient is fairly recent in medicine. This new awareness dates from the 1990s and the report "To Err is Human" by Leape (Institute of Medicine - USA, 1999) [Leape+2005]. Thus, in France, the statutory context aims to require professionals to evaluate their professional practices through Medical Experience Feedback Committees meetings (Comité retour d'expérience (CREX)and morbidity-mortality meetings revue de morbidité et de mortalité (RMM). During these meetings, they discuss and analyze their practices, declare and collect data on health care related to near-miss or adverse events (and/or potential risk events). They propose measures to locally improve their practices inside their departments basing on their own experience. Such practices nowadays form an integral part of the way health institutions. These practices are part of evaluation criteria to certify an healthcare provider. In other words, the French National Authority for Health Haute Autorité de Santé (HAS)delivers professional certification basing on criteria such as care quality, professional practice evaluations and many more. To help practitioners and get them to commit to a rigorous approach, the French National Authority for Health recommends a systemic analysis method to be used.

Using ALARM for collaborative analysis of a real serious adverse event during a meeting help them to structure their approach. When an adverse event occurs in the operating theater, the involved professionals organize a morbidity-mortality meeting to analyze the root causes with the aim of proposing and implementing measures to improve practices. The analysis of the chain of events that leads to the adverse event is a collaborative task. The meeting takes place a posteriori in a near future from the incident.

Before the morbidity-mortality meeting, a leader is in charge to prepare the meeting by finding out what happened and inviting to the meeting professionals who represent different trades. In the running morbidity-mortality meeting, they analyze the chain of events and try to find out a wide variety of contributing factors leading up to the studying incident. During the morbidity-mortality meeting, professionals are supposed to propose improvement measures. These improvement measures have to be deployed in a relative short delay by a responsible identified during the meeting. After the morbidity-mortality meeting, a morbidity-mortality meeting reporting have to be edited to the institution and particularly to the risk management staff.

The approach includes 6 stages:

1. collecting events that happened before and after the accident/near-miss/adverse event,
2. reconstituting the chronology of the accident/near-miss/adverse event,
3. identifying shortcomings in care (defined in relation to standards for good practices) - factual analysis
4. identifying their causes (contributory and/or influential factors) - systemic analysis
5. proposing measures for improvement

Vincent et al., [Vincent+1998] propose a description of the anatomy of an accident (see fig. 10.2) .

The systemic analysis which is supported by the French National Healthcare Authority (Haute Autorité de Santé) is composed of 7 defense barriers: (1) patient (2) actors (3) team (4) tasks (5) environment (6) institution (7) organization.

When we designed a scenario representing an irregular situation, predefined anomalies were dispatched and hidden throw the barriers. Designers provide large variety of actions and pieces of information to create diversion. As the consequence, the anomalies are drown in a sea of pieces of information. Furthermore, some actions or decisions might launch an uncontrollable situation. At the end, players are asked to identify what was wrong and what was right from their point of view. The professional process from ORION and ALARM methods has been reversed to force the students to identify their weakness and their strengths.

10.5 Methodology

The figure (see fig. 10.3) illustrates the method we used to design educational scenario for risk management training.

Factors that influence clinical practice

Institutional context
- Economic and regulatory context
- National Health Service Executive
- Clinical negligence scheme for trusts

Organisational and management factors
- Financial resources and constraints
- Organisational structure
- Policy standards and goals
- Safety culture and priorities

Work environment
- Staffing levels and skills mix
- Workload and shift patterns
- Design, availability, and maintenance of equipment
- Administrative and managerial support

Team factors
- Verbal communication
- Written communication
- Supervision and seeking help
- Team structure

Individual (staff) factors
- Knowledge and skills
- Motivation
- Physical and mental health

Task factors
- Task design and clarity of structure
- Availability and use of protocols
- Availability and accuracy of test results

Patient characteristics
- Condition (complexity and seriousness)
- Language and communication
- Personality and social factors

Figure 10.2 – Factors that influence clinical practices [Vincent+1998]

This approach has called for a step-by-step methodology. The steps of the process are detailed in the next paragraphs. The first one consists in video-recording real surgical situations. Surgery operations were recorded by the knowledge managers of the project. The set-up was fairly important: two fixed video recorders were placed in the operating room. One or more operators were filming using a third mobile camera for close-ups. A GoPro-type action camera was tied to the surgeon's forehead (see figure 10.4) so as to collect a first person view of the operation. On the basis of video clips recorded during real-life surgery operations, Devreux [Devreux+2014][Devreux2015] studied how professionals communicate

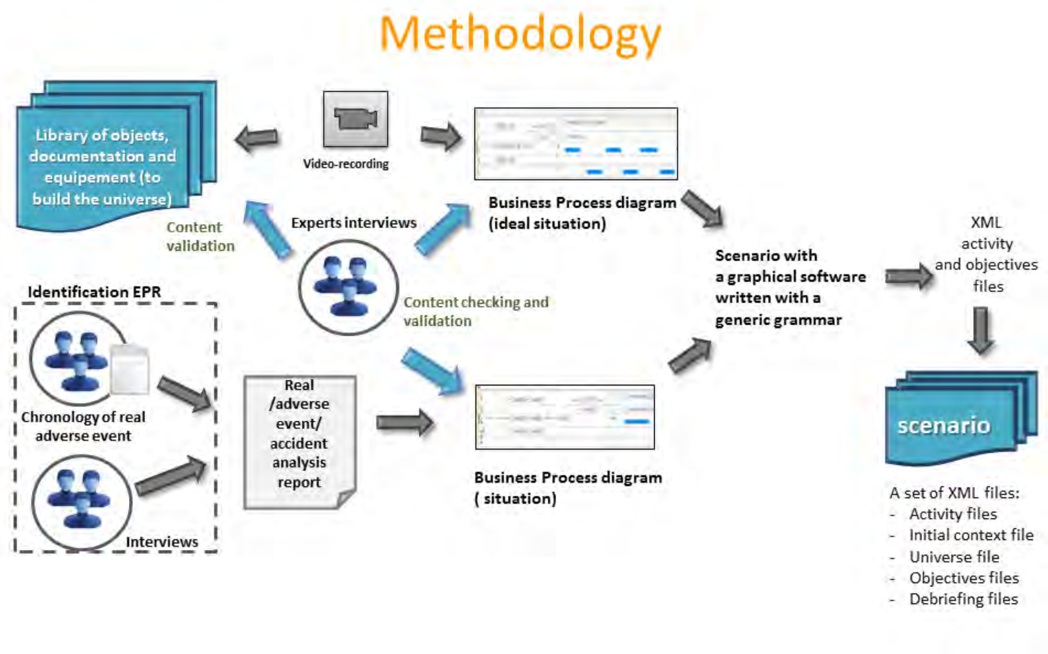


Figure 10.3 – Methodology used to design a risk management scenario.

according to the level of experience they have. This research highlights how experts adapt their strategies by collecting the same information from different sources in order to check their coherence. Several hundred combined hours were recorded for further analysis. A set of four representative surgeries were filmed during a one-year period such as brain tumor surgery, hip replacement surgery and cataract surgery. Within this period, the films were played back, analyzed and digitized into computer data by two knowledge managers, assisted by medical staff and healthcare professionals.

Figure 10.4 – A surgery being recorded in an operating room at the University Hospital of Toulouse.

10.6 Synthesis

10.6.1 Synthèse en français

Dans ce chapitre, nous avons présenté les enjeux sous-tendus par l'élaboration de scénarios pédagogiques destinés à la formation à la gestion des risques en équipe. Nous nous sommes orientés sur l'élaboration de deux types de situations. La première consiste à proposer aux étudiants une situation professionnelle dite "standard" dans laquelle aucune erreur n'a été commise a priori et aucun incident ne peut survenir a posteriori. L'enjeu consiste à s'assurer que les joueurs connaissent et appliquent les procédures de sécurité. La seconde consiste à proposer une situation dite "dégradée" i.e. qu'elle contient des erreurs qui ont introduites volontairement a posteriori. Cette situation favorise la survenue d'un accident ou d'un incident si rien n'est fait par l'équipe.

Une méthode a été élaborée pour construire de tels scénarios. Sachant que le probabilité de filmer un accident réel est extrêment faible, nous avons étudié les méthodes employées par les experts de l'analyses d'accidents réels dans les contextes socio-techniques complexes. Ces méthodes d'analyses dites systèmiques sont utilisés a posteriori pour déterminer les causes profondes d'accidents. Dans notre cas, il s'agit de s'inspirer de ces modèles à la fois pour introduire des anomalies sans le mentionner préalablement à l'équipe mais aussi dans le contexte de débriefing personnalisé. Ainsi, il sera possible de contrôler les incidents qui pourraient survenir. L'équipe sera alors confrontée à une situation imprévisible. Elle devra deceler les incohérences, échanger avec les autres membres de l'équipe, prendre les meilleures décisions afin qu'aucun accident ne survienne. Pour élaborer un scenario dit "standard", nous suivons la méthode décrite dans la figure 10.3. La première étape consiste à s'appuyer sur des entretiens d'experts, des enregistrements vidéo et la littérature scientifique pour apprehender l'activité professionnelle collective. La seconde étape consiste à modéliser l'activité collective afin ensuite de l'ancrer dans l'environnement virtuel.

10.6.2 Synthesis in English

Training teams on risk management keeps up the interest of many companies in industry such as aviation, nuclear, healthcare... as they work in dynamic and unpredictable contexts. One of the critical point is to create educational and entirely controlled training environments that support providers to train staff to improve their teamwork performance making them understand the importance applying or adjusting safety recommendations. The challenge consists in (1)representing a perfect initial situation with competitive experts who made zero error before the team must manage the current situation and (2)representing an irregular situation where experts made mistakes that can lead to an incident if the errors are not tracked and fixed in time. In this chapter, we have presented a method to design these two kinds of scenario. The first one consist in representing a regular situation embedded in a standardized scenario. It aims to train teams to apply safety recommendations and security process. To that end, we use the method described in Figure 10.3.

The second one represents an "irregular situation" embedded in a critical scenario. It aims to make team understand the interest of applying or adjusting policy safety procedure to avoid accidents. Designing such a scenario is more complex because it requires also analyzing the chronology of events before an accident and identifying the causal chain of events and their root-causes. The method described here has been inspired by the systemic method used to analyze real accidents that occurred in socio-technical and dynamic systems. Basing our thoughts on systemic methods analysis, we designed "irregular situations" both dispatching failures or errors in an initial perfect situation and providing erroneous available issues during a decision-making or inappropriate tasks in the cloud of possible tasks. Doing that, it is possible to conrtol adverse events that could occur. The team will be faced to an unpredictable situation and should be able to detect anomalies, exchange them with the others team members and make suitable decisions. While it is very hazardous to video-record a real adverse event, the method consists in relying experts interviews, video-records and scientist literature to describe the collective professional activity and probable adverse event. The second step consists in modeling the collective activity and anchor the activity into the virtual universe.

Chapter

11

A model to design collaborative educational scenarii dedicated for risk management training

Writing an interactive scenario consists in combining knowledge and interactions in the virtual environment (see 5). According to the situational cognitive theory [Lave+1991], a part of knowledge is in the virtual environment that provides the training context. Following the same idea, we refers to the affordance theory [Gibson1978] that defines a possibility of action available in the environment. These concept has been developed by Norman [Norman1991] who focuses the design on users and iterative development cycle analyzing tasks, activity and users' needs. These two approaches: interaction design and explicit representation of knowledge are crucial to design an educational scenario that intends to represent a professional activity.

11.1 Using BMPN for multi-player scenario modeling

11.1.1 Business Process Modeling Notation

In this research, we decide to use BPMN to model the teamwork: actions, communication and group decision making.

The first reason for this choice was the simplicity to represent the teamwork, especially information exchanges, individual and collaborative tasks. BP Diagram also enable us to represent parallel and synchronous tasks. This choice was also motivated by the necessary content validation step. In other words, it should be easier to interview experts and make them validate contents with a graphical representation of teamwork during a surgery. Another argument that supported this choice was the possibility to easily export the BP diagram to a set of XML files.

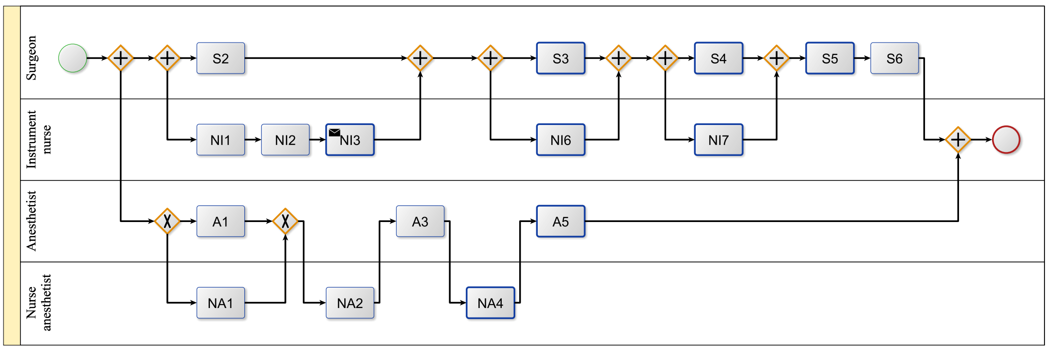


Figure 11.1 – The Business Process Modeling Notation enables the description of sequences of actions for several actors. Parallel (+) or exclusive (×) gateways are also used to model plans that must be achieved in parallel or plans excluding one another. The example of this figure describes a sample activity used for demonstrating our methodology. The label of the actions can be found in the table of figure 11.2.

Figure 11.1 illustrates the BPMN description of a toy-scenario.

To facilitate the collaborative work involving people from many scientific disciplines, and further scientific communication with a broader audience, we have defined terms for describing the activity that will be used henceforth unambiguously. A sequence (a BP diagram or a part of a BP diagram) describes the activity of one of several healthcare professionals. The activity is composed of interactions (activity nodes in the BP Diagram). Interactions can be i) actions performed on the environment, on the objects or on the patient, ii) communication or information exchanged with teammates or iii) decisions taken collaboratively with other teammates.

Figure 11.1 exemplifies a sequence of collaborative activity modeled using a BPMN diagram. Although it is possible to give a label to each activity node in the diagram, we have externalized

Character	ID	Description
Surgeon	S1	Display MRI
	S2	Wash hands
	S3	Put on gloves
	S4	Put on mask
	S5	Adjust surgery table
	S6	Set up lamp
	S7	Put MRI on the light box
	S8	Grab MRI
	S9	Take off gloves
Instrument nurse	NI1	Grab MRI
	NI2	Display MRI
	NI3	Tell surgeon MRI are set
	NI4	Put MRI on desk
	NI5	Light on the light box
	NI6	Help surgeon to put gloves on
	NI7	Help surgeon to put mask on
Anesthetist	A1	Set up monitoring equipments
	A2	Prepare drugs
	A3	Fill perfusion
	A4	Install perfusion
	A5	Anesthetize patient
	A6	Throw away drugs
Nurse anesthetist	NA1	Set up monitoring equipments
	NA2	Prepare drugs
	NA3	Fill perfusion
	NA4	Install perfusion
	NA5	Anesthetize patient
	NA6	Throw away drugs

Figure 11.2 – Description of the interactions from the sample scenario of figure 11.1. For the sake of demonstration, this example only shows a simplified set of actions merely inspired from the actual and much more complex procedure.

the labels in a separate table (refer to figure 11.2) to clarify the diagram. Figure 11.2 also shows that every interaction is related to an actor in the OR. When an interaction can be performed by several actors, it must be duplicated into several interactions (with the same label and content) each associated with one actor. This may be seen as a restrictive design constraint but is has beneficial implications on the AI (typically when one or several roles are assumed by non playing characters) and on the tutoring system (when each learner's actions must be evaluated).

The scenario modeled by the diagram is a toy-example but all the features necessary for understanding the BP-modeling process are represented. The diagram is divided into four lanes, each one representing a role in the collaborative activity: surgeon, instrument nurse, anesthetist and nurse anesthetist. The scenario reads as follows: The surgeon washes his hands while the instrument nurse displays the MRI on the light box and informs the surgeon. Then, the surgeon puts on surgery gloves and a mask, assisted by the nurse. Finally, the surgeon sets up his surgery environment, adjusting the chair and setting up the lamp. In the meantime, either the anesthetist or the nurse anesthetist sets up the monitoring equipment. The nurse prepares the drugs. The anesthetist prepares the perfusion. Then, the perfusion is installed on the patient by the nurse and the anesthetist sedates the patient.

Although fictional and simplified, this scenario reveals some invariable characteristics of the activity in the OR. We observed that the caregivers were working in pairs. The activity of the surgeon and the instrument nurse is most of the time collaborative. The anesthetist and the nurse anesthetist, however, seem to be interchangeable, and most of the time, any anesthetic-related interaction can be performed by either one of them.

As far as we have detailed the modeling process, interactions are the atomic pieces of the description of activity. Therefore the anchoring process shall be applied independently to every interaction. The idea is to characterize every one of them in terms of actual, noticeable or measurable changes applied to objects in the environment. In the next paragraphs we focus on the actions only, as communication and decision are characterized differently since they have no measurable impact on the objects in the environment.

Specifically, each action is described as a set of changes of the form *object.attribute←value*. For instance, an action labeled “Anesthetize patient" should be translated as *Patient.asleep←true*, meaning the attribute *asleep* of the object *Patient* has been assigned the Boolean *true* as new value. We can also imagine that, as a side-effect of this action, the anesthesia syringe pump has been emptied and therefore add to the translation: *Syringe_pump.contains_anesthetic←false* We could also imagine that the same action could have implications on monitoring equipment or many other objects, depending on the granularity of the action.

Describing the effects of an action highlights a problem related to the conditions under which the action is available. For instance, in the example above, let us say that the patient can not be anesthetized if the syringe pump is turned off. This matter leads us to consider that preconditions to an action should also be described along with the effect. The result is illustrated in figure 11.3 showing the XML description of the action mentioned above once the preconditions have been set. In contrast with preconditions, effects of the actions are now called post-conditions.

Preconditions have a dual role. Firstly, and most importantly, comparing in the game the preconditions of an action with the actual state of the environment will decide whether or not this action is available. Secondly, preconditions can be used for telling a legitimate action apart from a sentinel event. In the example given above, imagine we add in the scenario another action bearing the exact same label but with different effects: for instance one precondition becomes *Syringe_pump.set=false* and one post-condition becomes *Patient.asleep←false*. This new action is clearly a sentinel event where the anesthesia will fail due to a negligence with the syringe pump. If during the scenario, the team has carelessly forgotten to set up the pump, the “counterfeit” action will underhandedly be presented to the players instead of the legitimate one, leading to a sentinel event should the action be actually performed.

```xml
<action id="A5" actor="anesthetist, nurseAnesthetist">
    <label>Anesthetise patient</label>
    <preconditions>
        <pre object="Patient" attribute="asleep">false</pre>
        <pre object="Syringe_pump" attribute="on">true</pre>
        <pre object="Syringe_pump" attribute="set">true</pre>
        <pre object="Catheter" attribute="open">true</pre>
    </preconditions>
    <postconditions>
        <pre object="Patient" attribute="asleep">true</pre>
        <pre object="Syringe_pump" attribute="contains_anesthetic">false</pre>
    </postconditions>
</action>
```

Figure 11.3 – Every action from the BP Diagram must be described in terms of changes of states of objects in the environment. Objects can refer to furniture, appliances, documents or people.

Once all the actions of the diagram have been detailed as explained in the paragraphs above, a list of all the state changes can be collected from skimming the actions (this process is easily automated). The information held in this list is nothing less than the description of the environment inside which the players will re-enact the scenario, only this environment is not yet virtual but semantic, which means focused on the meaning of the activity rather than on the graphics. Figure 11.4 shows how the "raw" semantic environment can be reworked into a more readable diagram using the UML class diagram syntax elements.

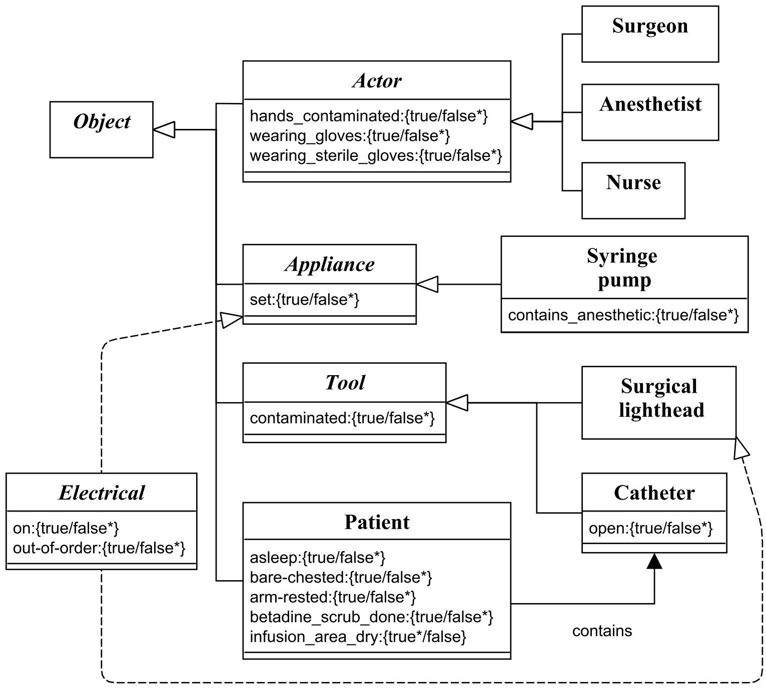


Figure 11.4 – The raw list of objects and attributes collected from the actions can be reworked and re-factored to resemble the traditional UML class diagram. This way, the information is more clearly read and potential mistakes in the descriptions (typos, doubles, etc.) are more easily found and mended.

Although in principle, the value of an attribute may be of any type (e.g. integer, character string, etc.) we used in practice Boolean variables. This choice was made to feel free to use Artificial Intelligence to manage virtual agent that could replace a missing player for example.

11.1.2 Weaknesses and difficulties to create an educational scenario with Business Process Diagram

The computerized human activity held in the BP diagrams cannot be used straightforwardly.

Firstly, the computer can neither understand the interactions labeled on the activity nodes of the BP diagram nor relate them with their expected impact or meaning in the environment. The process of anchoring the interactions into a semantic environment is a necessary step towards solving that problem.

Secondly, we need to anchor pieces of information related to tasks, equipment or documentation into the virtual environment.

Thirdly, we need to entirely control the activity in this educational environment. As the consequence, we choose to represent the semantic environment as a set of variables representing the states of every object mentioned in the activity. Therefore, we can control when the objects have to be displayed in the virtual environment, what graphical representation has to be used use, and what available actions have to be provided for the character to interact with.

Fourthly, we need to enhance regular expected paths with a cloud of possible paths to offer opportunity to manage freely the virtual educational situation.

Fifthly, we need to monitor the activity as a whole with global environment variables such as sterilized character. As an illustration, surgeon and anesthetist need to put sterilized gloves before cutting the skin or placing subcutaneous infusion or injection. If they put the sterilized gloves and touch non-sterilized object, they become non-sterilized that can be extremely dangerous for the patient.

Sixthly, we need to automatically deliver some messages or make available particular task when the state of the universe satisfy necessary prerequisites.

In conclusion, a serious weakness with the BP Diagram representation is that it does not enable us to entirely describe such an educational scenario as a whole. However, it allows to represent one regular expected path and help us to cross-check data with experts.

11.2 A specific grammar to describe synchronous and collaborative human activities in an educational scenario

At each time step during the game (i.e. each time the environment has been updated) the virtual environment should run through this simple algorithm:

1. Obtain from the game the list of all available tasks, as per the actual state of the semantic environment and the preconditions mentioned in every interaction.
2. Filter the interactions with respect to which character is playing
3. Attach those interactions to the objects in the virtual world, for instance in a contextual menu or as floating labels.
4. Wait for the player to select an interaction.
5. Process the interaction, update the environment and start the loop over.

We choose to fill these gaps elaborating a specific grammar that help us to answer to the points mentioned above.

The three main arguments that support the elaboration of a specific grammar to enhance BMPN approach are listed in the next paragraph.

Arguments Firstly, this specific grammar helps us to anchor into the universe the actions and pieces of information described in the collaborative diagrams and much more. Secondly it enables to multiply the number of tasks that can be made available for other team members at the same time whereas a BPMN Collaboration Diagram shows only one process to achieve a task. Thirdly, it allows to recognize predefined states of the system to deliver automatically pedagogical messages or launch automatic process such as game over, debate. . .

11.2.1 Attach the action to objects on the virtual scene

We need to answer how to initialize objects in the universe and how to attach tasks to some of them.

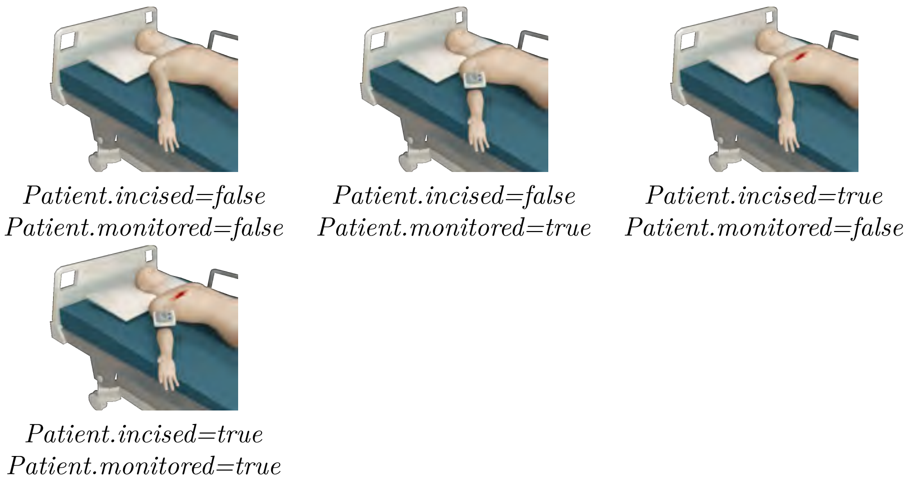


Figure 11.5 – Software objects in object-oriented programming are related to objects from the semantic environment. The attributes of these objects are related to visual cues whose graphical representation reflects the value of each attribute. This way, the semantic environment can be projected in the virtual world effortlessly.

Finding the object(s) concerned by an interaction is as easy as listing the object(s) mentioned in the description of the interaction in the BP Diagram.

Initializing objects consists in declaring the values of their characteristics. In an object-oriented programming language, the programmer manipulates objects. Each object is instantiated from a class, which describes the objects by their attributes and their methods. Attributes of an object define its characteristics and methods, to simplify, are functions describing how the object can be manipulated. In a graphical application, these software objects can be associated to graphical elements. If the object is to be displayed graphically then attributes may define a location, a shape, a color, a size,...

Each attribute in the semantic environment (like *Patient.incised* or *Patient.monitored*) is reflected by an attribute in the Patient class. Moreover, the Boolean value of each attribute of a class has an impact on how the objects instantiated from this class are displayed, for instance by parametrization their location, their mesh or a texture, etc. This is illustrated in figure 11.5 with two attributes belonging to the patient.

Following the same idea, methods can be associated to behaviors describing how the object can change or be modified. Changing the states of the objects requires setting new values to their attributes and this is done by means of calling the appropriate methods of the objects. The players are neither allowed nor given the ability to call these methods in the game. Instead, they are required to use the interactions described in the flowchart. Each interaction is described as a list of state changes and therefore selecting this interaction is the right way to perform the related changes.

Having a player select and perform an interaction is nothing complicated provided this interaction can be presented to the player in a user-friendly way.

The figure (see fig. 11.8) illustrates how a task is associated to a graphical object on the scene. The 'Target' parameter enables designers to indicate the name of an object on the scene to attach the task with.

The target object can be graphically represented either with an equipment or with an icon that provides a set of accessible actions. Actually, the traditional way to give a graphical representation to an interaction is to attach the interaction (as a floating label or as an item in a contextual menu for instance) to the object(s) concerned by this interaction, what is referred to as an affordance[Gibson1978][Whitehead1981][Gibson1978] on the object. In figures 12.212.3, the pictures show two samples of contextual menu used to list the available tasks.

11.2.2 Extend a BPMN regular path with new outlying sequences to build an educational collaborative scenario

Using the Business Processing Diagram does not allow to enhance the professional regular trajectory with other activity/tasks to to achieve a team's common goal. Enhancing the regular teamwork with other coherent professional activity allows to increase the number of possible paths to use to manage the situation.

The cloud of predictable paths is composed of:

- the best paths : the most suitable management according to the current situation (adjusting a the safety procedure for example)
- the regular paths: the path used by most of professional teams (applying and respecting a safety procedure for example)
- the non regular paths but reasonable paths
- wrong paths : non appropriate management of the current situation

Further more, we need a design environment able to provide tools and models to both enhance the BP Diagram with large number of tasks and to describe right available paths and predictable wrong paths.

The point is to provide enough tasks/actions and pieces of information to allow the characters to build their own path to manage the situation.To that end, new outlying tasks and new pieces of information have been added to enhance the regular ones. On the other hand, providing too much tasks/action can make the exercise more complicated and could need a specific training to use the environment and find where action can be launched in the virtual universe.

The video clips used for modeling each scenario are extremely detailed. During the modeling process, the first challenge is to determine the appropriate level of detail required for editing a coherent scenario.

To give an order of idea, the BPMN collaborative diagram of a simple educational scenario (welcome the patient in the operating room for example) is composed of more or less 500 actions, 150 pieces of information dispatched among 3 characters whereas the regular path is composed of 300 actions and 50 pieces of information.

The regular paths have been broken into phases according to professional activity phases.

11.2.3 Task to dispatch between team members while respecting their professional role

Biddle et Thomas [Biddle+1966] (who develop a theory of role) note that static assignment of tasks do not allow to represent the reality when staff realize collaborative teamwork.

Like Gerbaud et al. [Gerbaud2008] who worked on a VE to train military crew to repair and maintain Leclerc french army's armored transporter, we choose not to assign in a static way the tasks to a role. It implies to pre-assign some tasks to one or several roles depending on the reality assignment. Gerbaud et al. choose to develop a dynamic assignment depending on the actors who initiates the process. The section 11.2.10 shows how tasks can be assign to one or more roles and if a task is playable one or more times.

Each interaction having an effect on the environment, starting over the loop after each interaction involves re-evaluating the set of available interactions for each player, and so the scenario unfolds.

To that end, a particular grammar has been specified to filter all available tasks that can be displayed for each character's role and attached to interactive objects on the scene. This grammar is based on conditional models based on constraints.

Actions are attached to one or more character's roles.

```
<acteur id="P1" type="MAR" label="The anesthetist">
                <instance objet="P1">...
</acteur>
        <acteur id="P2" type="CHIR" label="The surgeon">
                <instance objet="P1">
</acteur>

<action id="B_10" actors="P1,P2".../>
```

In a same way, documentation access rights and equipment access rights are mentioned to enable character's role to specific elements in the environment.

11.2.4 Different categories of task in a collaborative universe

Analyzing video-records, four categories of tasks have been identified:

- individual and contextual action: action that can be done by one or more character when their prerequisites are satisfied.
- only once playable action : individual action that can be done by one or more character when their prerequisites are satisfied. Since one team member does it, the action is no more available for none of them.
- collaborative action: action that can be done simultaneously by two or more characters.
- automated action: action that is automatically launched when all their prerequisites are fulfilled.

For each one, a template has been defined. It is composed of a set of associated parameters such as pre-conditions and post-conditions, duration of the action, playable parameter, character's default role (from BP Diagram), character's roles (enable to do the current action), target (object in the 3D scene we must interact with), identity of the circle of actions in which the action must be displayed...

The figure 11.6 shows an extract of a graphical representation used to describe an educational scenario. Arcs have been voluntary erased and replaced by textual constraints to clarify the scheme.

Each rectangular shape represents a task. At the top of a shape, colored icons represent the character's roles which are enabled to do the current task. The purple icon is used to symbolize the anesthetist, the green one symbolizes the nurse and the orange one symbolizes the surgeon. This graphical representation of a task enables us to easily understand who is concerned by the task.

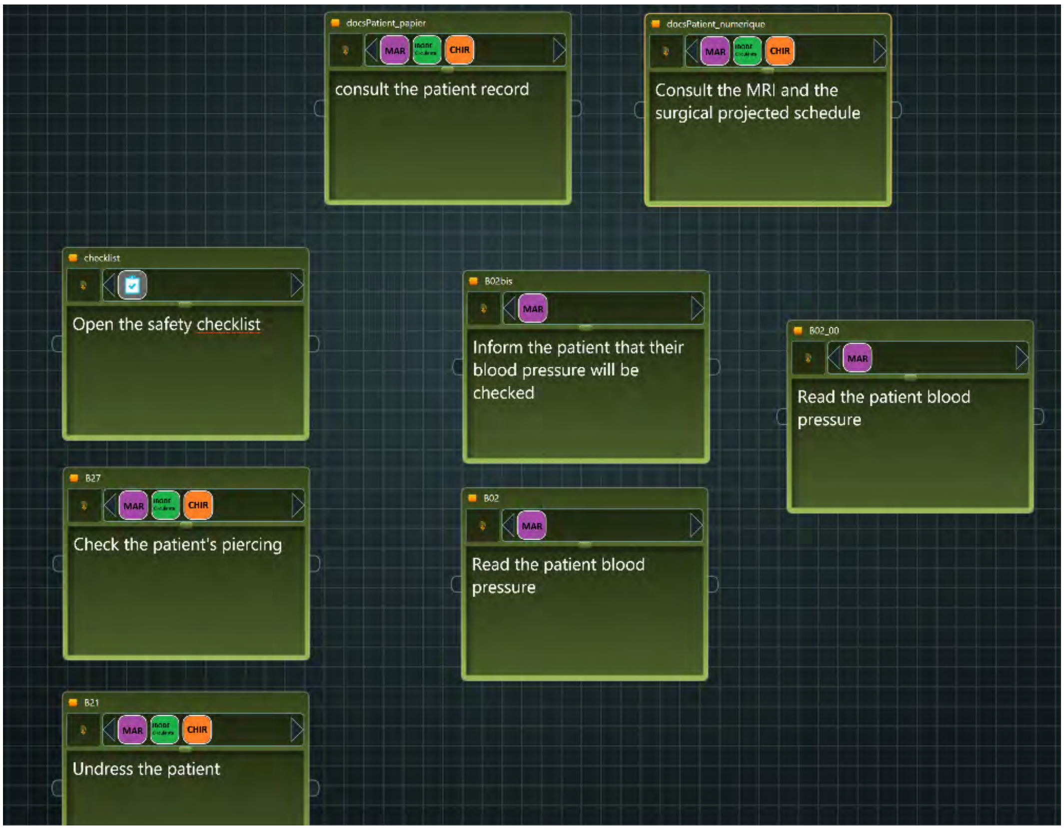


Figure 11.6 – Flowchart of a scenario.

The figure 11.7 shows the templates used to define different properties that compose elements of the educational scenario.

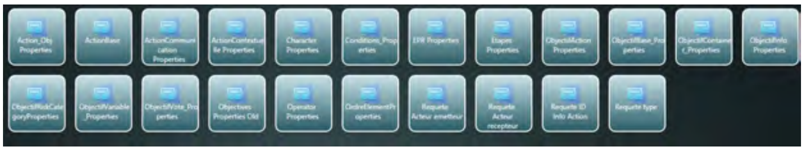


Figure 11.7 – Templates used to define elements of a scenario.

As an illustration, an action has several properties such as a category, an execution duration time, a target on the graphical environment…

11.2.5 Pre-conditions and post-conditions to support a dynamic activity

Firstly, we need to define precisely what are the pre-conditions and post-conditions for a task. Pre-conditions are a set of prerequisites that must be satisfied to make a task available to a character's role. Post-conditions are a set of parameters that changes immediately after the action has been accomplished or/and set of pieces of information that have been collected doing this action. As an illustration, the task 'read the patient's blood pressure' is composed of both post-conditions and pre-conditions. The post-conditions are:

```
        POST-CONDITIONS:
                broadcast(blood_pressure,this);
                hide(blood_pressure_monitor);
        PRE-CONDITION:
                display(blood_pressure_monitor)
```

The grammar *"broadcast"* is used to send a piece of information to the character who launches the action.

```
        broadcast(piece_of_information,value);
```

The grammar *"hide"* and *"display"* helps to display or hide a particular object when a task is on progress.

```
        hide(object_on_the_scene);
        display(object_on_the_scene);
```

11.2.6 A condition to know who knows what

At any time, the game engine needs to know whose character's role knows what. The grammar below can be used to check if a piece of information is known.

```
        know(id_character_role(List (X,Y,Z)), piece_of_information_to_know)
        where
        id_character_role is a set of unique identifier
        of a character's role
        and
        piece_of_information_to_know is the unique identifier
        of a piece of information.
```

This condition allows to combine different pieces of information and push a new piece of information resulting from the logical combination. As an illustration, a character knows the pieces of information A and B, the piece of information C results from A and B, as the consequence, the character needs to be able to manipulate the piece of information C. The main goal of the educational scenario is not to check if the player is able to diagnose and combine some pieces of information but how they are able to select the most relevant, communicate them to the others and argue their opinion on what is the best to do.

11.2.7 A condition to know if a task have already been achieved

At any time, the game engine needs to know if a task has been achieved or not in order to propose new tasks, new sequences or to close the game session. The grammar below can be used to check if a task has already been achieved.

```
        objective(id_objective_to_check, boolean(true,false))
        where
        id_objective_to_check is the unique identifier of an objective
        relative to a task
        the boolean value is true when the objective has been validated.
```

This condition (associated with an objective) allows to separate the whole team activity in shorter sequences providing only tasks relative to a shorter sequence. As an illustration, it is not interesting to provide task to cut the patient's skin whereas the patient is not asleep. As the consequence, the task "cut the patient's skin" will not be available since the patient is not asleep. To that end, positioning a pre-condition on the task depending on the objective

"Asleep the patient" help us to reduce the number of logical tasks to provide to the team members.

11.2.8 A condition associated to a parameter

At any time, the game engine needs to know the state of an instance on the scene. The grammar below can be used to check the value of an attribute.

```
equal(id_object, environment_variable, value)
where
id_object is the unique identifier of an object on the scene
environment_variable is the attribute associated to the object
the value is the value to check with the current value.
```

This condition helps to calculate some numerical game parameters such as the patient's health, level of anxiety... The figure 11.8 illustrates how to increase a parameter using a specific syntax in the post-conditions frame.

11.2.9 A condition associated with an object "container"

At any time, the game engine needs to know an object is on the scene and its location. The grammar below can be used to check this point.

```
contains(container_id, object, boolean(true,false))
where
id_object is the unique identifier of an object on the scene
environment_variable is the attribute associated to the
object
the value is the value to check with the current value.
```

This condition helps to check if an object is part of another one or if it is placed under another object. As an illustration, when the nurse staff prepare the surgical table, they place the bed surgical sheepskin for pressure sores prevention, the surgical sheet and the face-plates on the bed. As the consequence, the task 'Prepare the surgical table' should only be available if the surgical bed does not contain the surgical armrests, the headrest or the surgical sheet. In conclusion, positioning a pre-condition typed "contains" help us to offer the opportunity to provide or not this task in the current cloud of available tasks.

11.2.10 Use case

The figure 11.8 shows an illustration of a task that has been defined with values and parameters using a predefined template and the grammar to describe pre-conditions and post-conditions.

An extract of a sample of XML files relative to a collaborative task is displayed below.

```
      <?xml version="1.0" encoding="windows-1250"?>
<action id="B22" type="CONTEXTUELLE" voidable="true" replayable="true"
      requestable="true"      collaborator="" actorsDefaut="P4,P1,P0"
actors="P4,P1,P0" description="Move the patient to the operating room"
      target="PATIENT"        destination="PATIENT" zone="Trunk"
      iaExecutable="true" cible_02="" icon="COLLAB">
  <preConditions>
    <preCondition type="OBJECTIF" objectif="STEP_objective_03" complete="false" />
    <preCondition type="EGAL" objet="TABLE_OPERATION" attribut="prepare"
                  valeur="true" />
    <preCondition type="OBJECTIF" objectif="Obj_LOCK_v3_rep1" complet="false" />
```

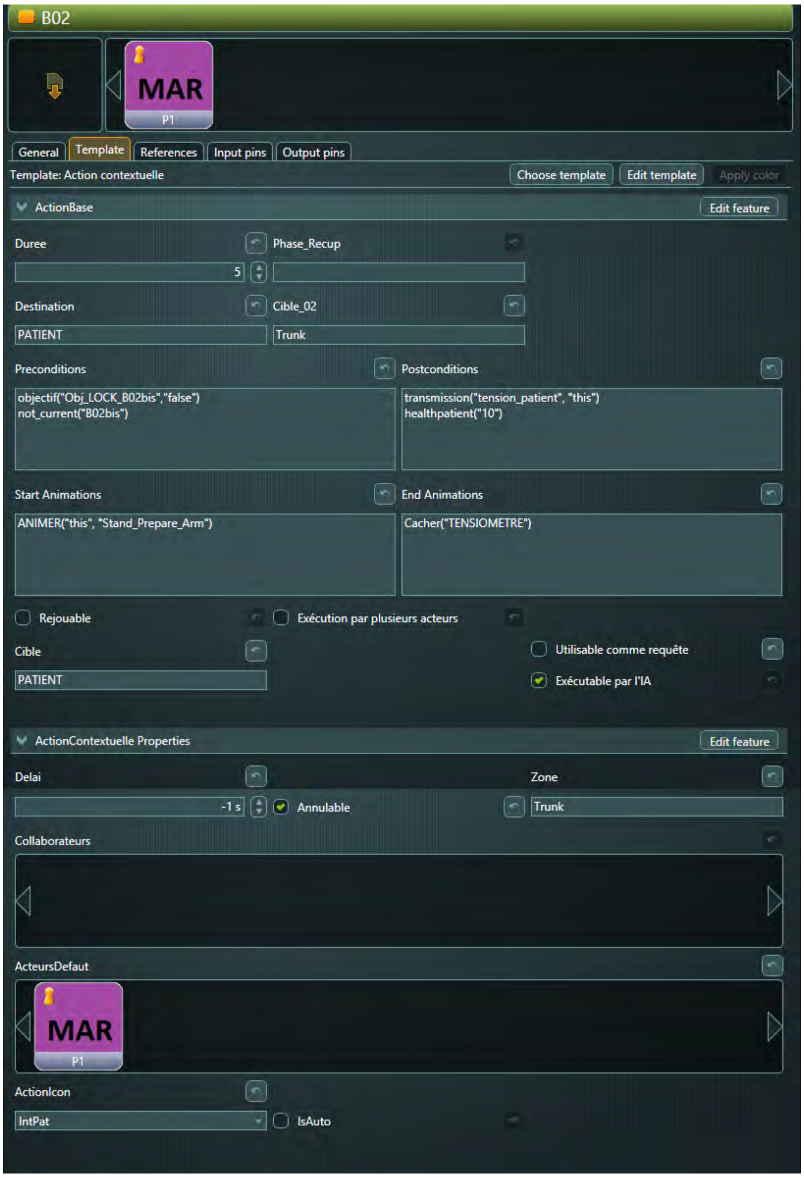


Figure 11.8 – A task is defined by setting values and conditions according to their template. Conditions are defined using a specific grammar.

```
  </preConditions>
  <postConditions>
    <postCondition type="VOTE" vote="v3" />
  </postConditions>
</action>
```

A task is described by an action tag which is composed of different attributes:

- id: the "id" defines the unique identifier of the task
- type: this attribute defines the category of task (contextual, automatic...)

The automatic actions enable us to launch automatically a debate, display automatically an educational message (alert or announcement for example) or stop the game session in case of success or failure. The listing below illustrates how the "automatic action" concept is used to launch automatically a game over. In this example, one of the possibility to lose is to check "No" for the item concerning the patient's identity on the safety Checklist. Doing that, the game is over and a message must be displayed on the screen to inform the team they failed.

```
<?xml version="1.0" encoding="windows-1250"?>
        <action id="gameover_item2_1" type="AUTO" voidable="false"
        replayable="false"      requestable="false" collaborateurs=""
        acteursDefaut="" acteurs=""
        description="Checking No for the item concerning
        the patient's identity on the safety Checklist"
        cible=""  destination="" zone=""
  iaExecutable="false" cible_02="" icon="NOICON">

                <preConditions>
                        <preCondition type="OBJECTIF" objectif="ObjEtape_E00"
                        complet="false" />
      <preCondition type="CHECKLIST" item="item2_1"
                        yes="false" no="true" na="false" />
    </preConditions>

    <postConditions>
      <postCondition type="GAMEOVER" win="false"
                        label="The checklist has not been correctly checked"
                        risque="risk_02" />
    </postConditions>

  </action>
```

```
<?xml version="1.0" encoding="windows-1250"?>
  <action id="B22" type="CONTEXTUELLE" voidable="true" replayable="true"
        requestable="true" collaborator="" actorsDefaut="P4,P1,P0"
  actors="P4,P1,P0" description="Move the patient to the operating room"
        target="PATIENT" destination="PATIENT" zone="Trunk" iaExecutable="true"
        cible_02="" icon="COLLAB">
    <preConditions>
      <preCondition type="OBJECTIF" objectif="STEP_objective_03" complete="false" />
      <preCondition type="EGAL" objet="TABLE_OPERATION" attribut="prepare"
                        valeur="true" />
      <preCondition type="OBJECTIF" objectif="Obj_LOCK_v3_rep1" complet="false" />
    </preConditions>
    <postConditions>
      <postCondition type="VOTE" vote="v3" />
    </postConditions>
  </action>
```

11.3 Scenario content checking and validation

Once a scenario has been designed, or during the course of the design process, two types of validation can be carried out. Both are important at the designing stage because they can substantially lighten and facilitate later user-testing of the game by detecting obvious deadlocks, inaccuracies in the scenario, or hidden flaws in the narrative that beta-testers would be unlikely to encounter.

The first form of validation is content validation. It aims to ensure that the content of the scenario is coherent with respect to the activity captured in the first place and actually reflects the original objectives of the scenario. Content validation of a scenario relies on domain experts reviewing the activity described on the nominal and the degraded paths. Thanks to the notation, this form of validation has revealed intuitive and effective, as errors or ambiguities resulting from misunderstandings were pointed out by the experts.

The second validation process deals with eradicating possible incoherence, dead-ends or infinite loops that could structurally prevent the players from reaching one or several objectives of the scenario. To achieve this process, we have engineered an automated method based on the use of formal grammars. The rough idea is to replace each action by a production rule and to develop the grammar from a start symbol representing the initial state of the scenario until expectantly reaching the end symbol representing the final state of the scenario. The method is similar to algorithmic validation, only applied to BP models.

11.4 Synthesis

11.4.1 Synthèse en français

Dans ce chapitre, nous avons présenté la méthode utilisée pour construire et modéliser un scénario pédagogique destiné à la formation à la gestion des risques par équipe. Se basant sur des entretiens avec des experts, des enregistrements vidéo d'opérations chirurgicales réelles et leurs analyses, nous avons modélisé l'activité des équipes du bloc opératoire. Différents modèles de représentation de cette activité ont été identifiés : ontologie, réseau de Petri, réseaux bayésiens, Business Process Modeling and Notation (BPMN). Compte tenu du nombre important de tâches et d'informations à manipuler pour une équipe constituée de plusieurs personnages, les représentations d'activité collaboratives par le biais d'ontology et de réseaux bayésiens ont été écartées. Le modèle de réseau de Pétri ne permettant pas de représenter les tâches collaboratives et simultanées a été écarté à son tour. Une première représentation a été réalisée avec les diagrammes du modèle BPMN car la retranscription de tâches synchrones, parallèles et des flux d'informations est gérée par ce modèle. Malheureusement, construire un scénario d'apprentissage nécessite d'enrichir la trajectoire standard modélisé dans un diagramme BPMN. Il s'agit de proposer aux utilisateurs de nombreuses autres possibilités que celle décrite dans le digramme BPMN mais aussi d'ancrer les activités dans l'environnement graphique tout en respectant les contraintes liées à l'activité professionnelle réelle. Pour cela, une grammaire spécifique a été élaborée. Elle permet de rendre accessible certaines tâches à plusieurs membres de l'équipe, de contraindre leur accessibilité, de synchroniser à tout moment l'environnement ou encore de monitorer l'activité. Cependant, modéliser l'activité collaborative n'est pas suffisant, il s'agit ensuite de l'ancrer dans l'environnement et d'y associer des interactions qui devront être mises à disposition.

11.4.2 Synthesis in English

In this chapter, an innovative method to design an educational scenario for risk management involving team members has been described. The first step of our works is based on expert's interviews, video-records of real surgeries that have been analyzed. From this work, the teamwork activity in an operating room has been modeled. Different models have been studied to represent the teamwork activity such as Ontology, Petri Networks, Bayesian Networks, Business Process Modeling and Notation (BPMN). The large number of individual tasks that must be represented leads us to eliminate ontology and Bayesian networks. Petri Networks has been also eliminated because they do not allow to represent collaborative and synchronous tasks. A firts representation of the teamwork activity has been modeled with BP Diagrams because synchronous tasks, collaborative tasks, parallel tasks and information flow can be represented using the BPMN model. Unfortunately, building an educational scenario is not resume to a minimalist description of the regular trajectory of a teamwork activity. It requires to enrich the nominal and regular trajectory with a large number of possible and coherent tasks that can be proposed and chosen by players. To that end, a specific grammar has been created. It allows to provide public access tasks to many team members, to limit tasks access to few team members, to synchronize in real-time the virtual world, to monitor the teamwork activity. . . However, modeling collaborative activity is not sufficient. It also requires to anchor these tasks in a virtual world, associate them with virtual objects and define graphical interactions that allow users to interact with the virtual universe.

Chapter

12

A methodology for prototyping the collaborative virtual environment for training

The environment represents with great fidelity the structure and complexity of an operating room. It allows controlled manipulations of the decision context and controlled information available to the subjects. It is composed of an operating room (medical equipment, patient record, drugs. . .) and avatars for the patient, the surgeon, the anesthetist and the nursing staff. It aims to train them on non-technical skills. They need to communicate, act, share information and make the most suitable decision with respect to the situation. The individuals, grouped in a virtual team, play the role of professionals in the virtual scene of the operating room system.

Figure 12.1 shows an example of configuration. Each player and the trainer use a computer connected to a local network. The trainer launches a party with a particular scenario, then, each player can join the party and choose their role.

Figure 12.1 – Each player uses a computer connected to a local network and accesses to the collaborative virtual environment.

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 working temporal continuum 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.

The methodology consists in dividing the prototyping in two big steps to design and develop models and interactions. To that end, we applied the design-based research methodology [Obrenović2011] that relies on rapid prototyping to evaluate ideas in frequent short cycles.

The first step consists in prototyping a 2D collaborative environment which allows team members to accomplish tasks and to establish basic communication and decision making. It aims to validate generic models and basic interaction metaphors to mimic basic communication and decision making process. This prototype provides only one particular scenario based on a simple set of actions and limited number of information distributed among 3 characters in a 2D virtual environment. Each character can not move or can not angle to another part of the room but has a global view of the room.

The second step consists in prototyping a 3D collaborative environment, re-use and enhance validated models from the first step. New and more sophisticated models have been designed on the basis of those validated at the first step. The 3D collaborative environment has been realized in partnership with two companies: KTM Advance and Novamotion.

Finally, playful elements, graphical interactions, animation, sounds... have been added to enhance the immersive collaborative experience.

The next sections present more details about these two prototypes.

12.1 2D multiplayer and real-time environment

The scene is represented as 2D view and icons allow users to access to a specific documentation(see Fig. 12.2). Some particular icons allow users to access to specific features. As an illustration, the security manager is the one who can trigger a debate on a security topic (see figure 12.2). Users are presented with a first-person perspective of the environment. Their character is not allowed to move freely. 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, anesthesia machine... Each character is located at a specific area on the scene.

Figure 12.2 – The virtual universe is represented in 2 dimensions. It provides basic communication system and contextual action system that allow users to experiment virtual teamwork.

The JavaScript-based environment *node.js*[1] was used for the server logic. JavaScript was used along with an HTML/CSS home-made environment. For every object in the semantic environment,

1. A corresponding class must be programmed in the game engine.
2. A 3d model must be designed and associated to the class.
3. For each attribute of the object in the semantic environment, a corresponding attribute must be defined in the software class representing the object.
4. Methods must be programmed for changing the attributes of an object. Graphical animations or visual modifications (changing the texture, the lighting, the size or the position of the object) must be integrated within those methods so as to make a modified attribute reflected by a graphical modification in the virtual environment.

This environment has been deployed on a *Debian Server* using an Apache Web Server with *Phusion Passenger*[2].

12.2 3D multiplayer and real-time environment

The scene takes place in a 3D universe where the characters can move to predefined areas (see Fig. 12.3). The universe is composed of 3D equipment, 3D virtual patient and 3D characters.

[1] http://nodejs.org/
[2] https://www.phusionpassenger.com/

The characters are located at the beginning on predefined area. They are not allowed to move anywhere they want. They can move only to limited point-zones in the environment according to its real professional location. An animation is launched when the user points and clicks on an icon to realize a task. As a result, its character move to a specific area to realize the selected task.

Figure 12.3 – This 3D immersive virtual universe is based on multiple complex modules. A global architecture is structured around modules such as : game session management module, scenario management module, task management module, documentation module, communication manager module. . .

This prototype uses more complex models including dynamics information and collaborative educational objectives designs. It provides playful elements and features approved by experimental play-tests with the first one prototype. Contrary to the first prototype, it can be used with a large variety of scenario and it is able to manage at least few game sessions in parallel.

Contrary to the first prototype, it embeds an artificial intelligence module to control missing team members i.e. even if some members are missing, the party can be launched thanks to an artificial intelligence which is able to control and replace them [Sanselone+2014].

The game engine used to develop this prototype is Unity3D. Visual objects in the graphical scene are represented by software objects in JavaScript or C# associated with a mesh, a material, a texture, a matrix defining a position and a rotation in space, and other components like colliders for helping with the interactions.

12.3 A client/server architecture

A client/server architecture must be used to make this work. Each player runs its own version of the game, although synchronized with the others. The role of the server is to hold the data representing the semantic environment. Centralizing the semantic environment is very important to avoid having to cope with discrepancies when several players interact with their own version.

The server also manages the communication with multiple clients. Each client embeds the graphical environment reflecting the semantic environment and scripts managing the computer interactions between the player and the game. Since the game is immersive, the virtual world is displayed differently on each client, depending on the point of view of their avatar inside the environment (cf. figure 12.4).

Yet, although each player perceives the world from their own point of view, the world displayed is the same for everyone.

Figure 12.4 – This 3D immersive virtual universe provides a personalized graphical view from each character.

How is the synchronization managed? Every time an interaction is selected by a player, the client informs in real time the server by sending a message. The server analyzes the interaction and updates the semantic environment as per every state change described in the interaction. The list of those changes are then broadcast to all connected clients, including the sender. Upon receiving the changes, each client synchronously calls the associated methods on the concerned objects which contains the visual effects or the animations to cast on the virtual environment. That way, each time one action is performed by a player, it is instantly noticed visually by everyone. The back-and-forth communication between the client(s) and the server is on average in the order of 8-10 milliseconds in a local network, which is barely noticeable by the players.

12.4 Architecture

The environment is not based on centralized model but uses a central core that links different modules together. The figure 12.5 offers a general view of the main components that compose the core. This view is broken into 3 phases. It must be read from right to left. On the right, the column relates the connection step. The "connection step" is the first phase when all players join the party and choose a role. In the middle, the column focuses on the game session. The "game session" is the phase from the beginning of the game until the team succeeds or fails. On the left, the last one concerns the debriefing and feedback displayed to the players at the end of a game session. The "Debriefing step" is the phase when the core shows to the team their results comparing to the educational objectives.

All the components are described in the sections below.

12.4.1 Game Connection Module

This module manages the start of a party. One of the participant launches a party and the others can join the ongoing party. As in a chat room, users 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. The first and the second prototype do not support the same registration system neither the same game module connection.

12.4.2 Scenario Management Module

The scenario management module provides a set of available scenario. A scenario can be launch regarding to its briefing, the character's role needed, the surgery focused, the skills to perform (only available for trainers) and the risks being included (only available for trainers)... It

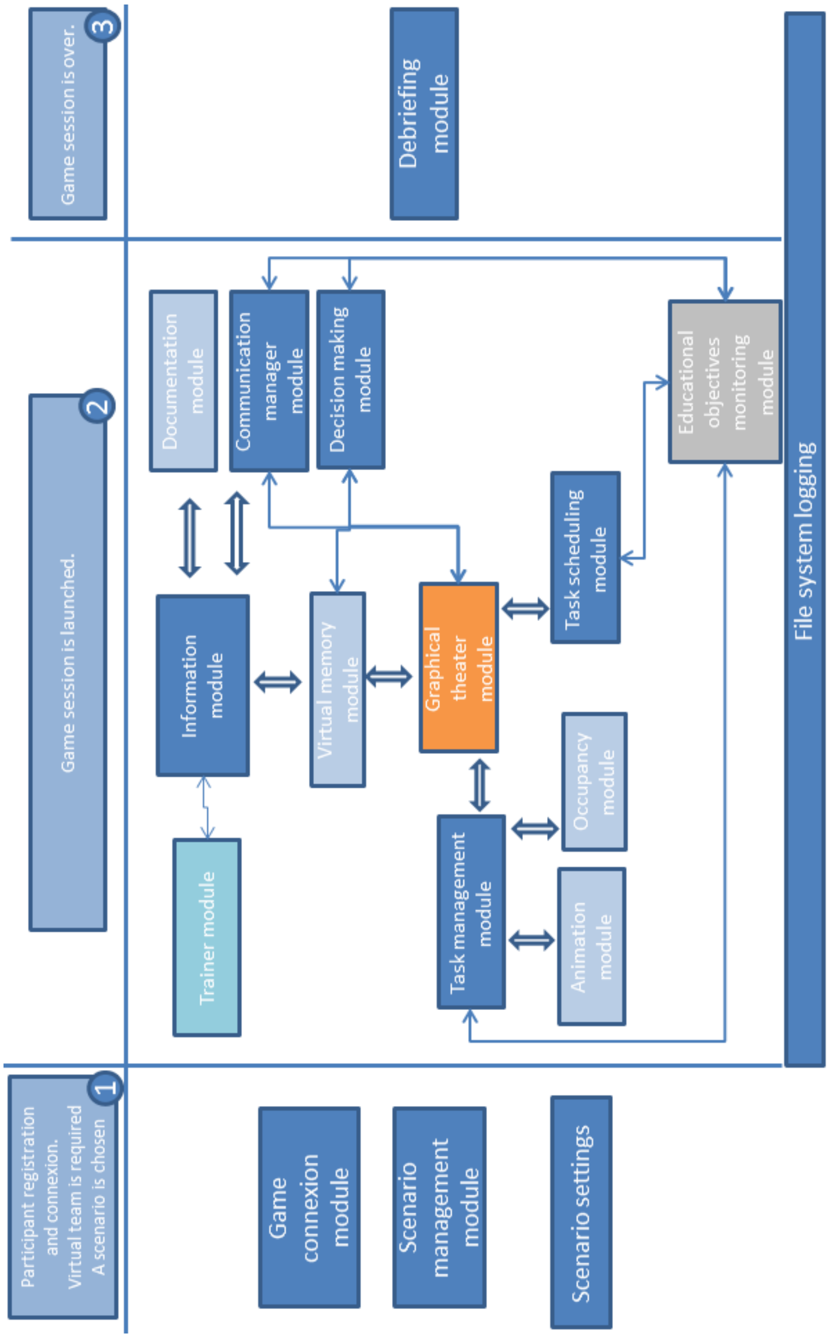


Figure 12.5 – Global architecture of the virtual collaborative socio-technical environment for training

is possible to run a learning session even if the team is not complete. Then, an artificial intelligence(AI) controls and simulates the character's behavior of NPC[Sanselone+2014]. In this case, autonomous agents replace missing members. The Scenario management module informs the AI engine on the missing team members that must be controlled by artificial characters.

12.4.3 Scenario Settings Module

The scenario settings module lists data relating to the initial situation such as character's roles involved in the scenario, the steps of the scenario, the categories of risks that may conduct to an incident, the objects and equipment to display on the scene. . .

12.4.4 Task Management Module

The task management module is used to display dynamically to each character's role the set of current available actions.

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 the universe (see Fig. 12.6). 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.

Figure 12.6 – Second prototype: The virtual 3D universe contains communication system and contextual action system that allow users to experiment a socio-technical situation.

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

- individual
- collaborative task

12.4.5 Virtual memory module

The virtual memory module is a crucial module that enables to synchronize the character's memory with the player's memory while pieces of information being collected during the party. The module is presented in details in 13.2.

12.4.6 Information module

This module manages all the pieces of information that can be used or combined in a game session, all questions that can be asked, all interjections. . . More details are available in section 13.1 and section 13.10.

12.4.7 Documentation module

This module manage the access of documentation according character's role and information that can be collected and stored in the character's virtual memory. More details are available in section 13.5.

12.4.8 Communication Manager Module

This module manages the communication between each team member. It allows the players to send piece of information, broadcast or receive a piece of information, ask and answer questions, launch an interjection, listen information exchanged between 2 other team members. . . The Chapter 13 details its features.

12.4.9 Decision making Module

This module manage the synchronous debate while a collaborative decision making task is launched. The Chapter 14 brings more details.

12.4.10 Educational Objectives Monitoring Module

This module monitors the teamwork activity and compares at any time if an expected objective is fulfilled. 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. The chapter 15 details this module.

12.4.11 Debriefing Module

The debriefing module displays feedback, error messages, success messages. It synthesizes the activity and skills performed regarding the expected educational objectives.

12.4.12 Trainer Module

This module enables the trainer to join or launch a party. This module provides to the trainer a GUI that displays a global view of the teamwork: their activity, their discussion. . . The trainer is also provided with the ability to intervene, alert the team with predefined pieces of information or free text-chat bubbles, pause or stop the game session.

12.5 Synthesis

12.5.1 Synthèse en français

Dans ce chapitre, nous avons présenté la démarche utilisée pour développer les modèles et les interactions dans l'environnement. Nous nous sommes appuyés sur des cycles de développement courts et itératifs pour évaluer les idées mises en œuvre. Deux prototypes ont été développés afin de s'assurer de la validité des modèles de base avant de développer des modèles plus sophistiqués. Le premier prototype s'appuie sur un environnement multi-joueurs synchrone en deux dimensions dans lequel les modèles de bases : relatifs à la gestion des tâches, des communications et des prises de décisions ont pu être expérimentés et validés (voir chapitre 18). Le second s'appuie sur un environnement multi-joueurs 3D temps réel dans lequel les modèles validés ont été enrichis. L'architecture globale a été présentée. Elle est structurée autour de nombreux modules tels que le module de gestion de partie, le module de gestion des actions... (voir Fig. 12.5)

12.5.2 Synthesis in English

In this chapter, the scientific approach to design models and interactions has been presented. It consists in applying the design-based research methodology [Obrenović2011] that relies on rapid prototyping to evaluate ideas in frequent short cycles. Using this methodology, two prototypes have been developed. The first one was used as a basis to validate primary models before developing more advanced models. Its environment is a 2-dimension digital environment where models relative to multi-player management module, task management module, communication module and decision making modules have been progressively established, experimented and validated for most of them (see chapter 18). The second prototype is based on a 3-dimension digital environment where models (from in the first prototype) have been validated and enhanced. These two prototypes share common modules, features and interactions. All their sharing points have been presented. A global architecture structure the software. It is composed around modules such as: game session management module, scenario management module, task management module, documentation module, communication manager module... (see Fig. 12.5).

Chapter

13

Communication system

The analysis of existing communication systems made in chapter 6 shows that none studied communication systems suits to a virtual learning environment that aims to control topics of dialogue and information exchanges in real-time. This section describes an innovative communication system that makes possible virtual and controlled dialogue between teammates. The system tries to respect implicit conversation rules to ensure a minimum of coherence in the conversation. The communication system does not allow 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 13.1 illustrates the main features of the communication system.

13.1 Information

Information seeking and individual activity are bound intrinsically. Leckie et al. [Leckie+1996] and Reddy et al. [Reddy+2010] 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

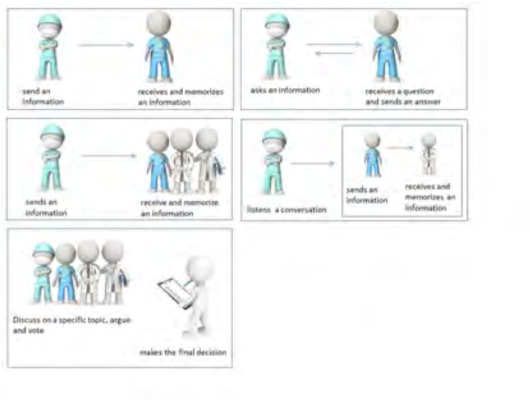


Figure 13.1 – An overview of the communication system.

of interaction between a single user and technology and (2) the emphasis on individual, not on collaborative work."[Reddy+2006]

Inside the virtual environment, 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 (see Fig. 13.2).

Figure 13.2 – By clicking on an interactive menu, the user can realize a specific task.

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 13.1)

Inside the virtual environment, every piece of information is represented as a floating bubble where the label is displayed (illustration in Fig.13.8) along with the source(s) or sender(s) of the information which are depicted by thumbnails representing the corresponding characters. The background color of the bubble also gives a hint regarding what or who is concerned by the information. Table 13.2 lists the colours used in the game.

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 13.1 – 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 ?

Table 13.2 – 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

Table 13.3 – 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 four 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 13.4 lists the different meanings associated to the attribute `Patient.arterialpressure` depending on these contexts.

13.2 Virtual memory of a character

An important aspect of the process described above is the ability for each participant to build and maintain a personal (as opposed to shared) knowledge of the situation. A virtual

Table 13.4 – 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?

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. As a consequence, 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 13.3). The virtual memory panel displays piece of information

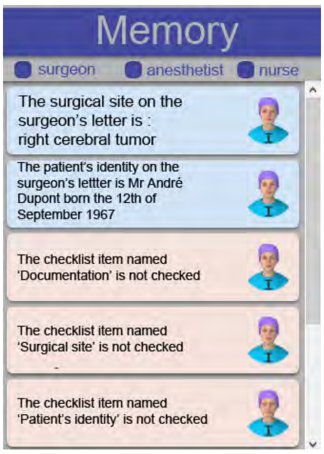


Figure 13.3 – The virtual memory of a character contains information acquired.

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 13.5 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 13.5 – 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

13.3 Activity Panel

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 13.3. This option was selected to design the first prototype.

The second prototype embeds a module that manages the characters' activities. This module displays graphical information to make players understand their teammates' current activity. The character's animation attached to a task is launched to make character move to predefined targeted areas in the universe. At the same time, the current task is displayed on a panel at the top-left corner of the screen 12.3. A picto is used to represent the character's role and the current task that they are doing is displayed under a progress bar. This progress bar indicates the duration of the task 13.4. Some particular technical actions are represented throw short centered animations over the virtual character who is doing something (see fig. 13.5).

The information displayed throw this panel helps players understand what's going on and gives an indication on the level of attention a teammate pays if you want to discuss with.

Figure 13.4 – Second prototype: the activty panel displays the current tasks of each character's.

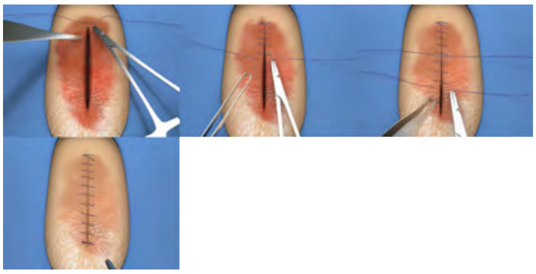


Figure 13.5 – A billboard displays successively the pictures that makes an animation to make teammates rapidly understand the current task to the others.

13.4 Conversational panel

On GUI, a visual panel help player to see the conversations between avatar's team : an history chat panel (see fig. 13.6) 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.

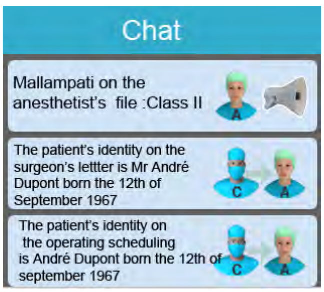


Figure 13.6 – The chat panel displays the chat history.

13.5 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:

- 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 13.4). 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 13.7, 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.

13.6 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

Figure 13.7 – 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.

bubble and dropping it into to his character. In figure 13.8, 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).

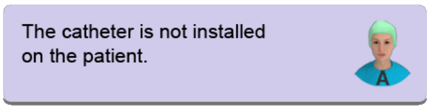


Figure 13.8 – An information bubble representing 'the catheter is not installed on the patient" which was sent to the player by the anesthetist nurse.

13.7 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. Another metaphor illustrates the fact that someone could hear but not listen a conversation. This situation has been treated by making available of the conversation content between two other players in the Conversational Panel (see section 13.4). If a third party wants to listen what piece of information have been exchanged between character B and character C, they must click on the bubble that represents the dialogue between B and C to discover its content. It is important to note that the bubble is temporary click-able during 5 seconds. Another metaphor has been implemented to mimic the situation where someone is occupied doing a task while their colleague tries to talk to them. In this case, the bubble of information sent contains an incomprehensible message. The incomprehensible message is automatically built by erasing two other letter on the initial piece of information. As an illustration, if the initial message is ”Patient’s identity: John Robert”, the incomprehensible message should be ”Pa..en..s id..ti..: Jo.. Ro..rt”. A message is also sent to the sender to inform them that their message has not been completely received because the receiver was busy.

13.8 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 13.4). 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 screen13.9, 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 13.10) 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.

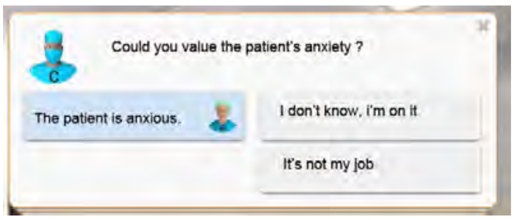


Figure 13.9 – A window pops and contains both the question, the generic answers and the current specific response if the character knows it.

Figure 13.10 – 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.

13.9 Asking a teammate about their activity

In practice, a significant part of realized tasks is likely to be accomplished by the player himself at their own intention. Other part of actions could be realized because a team member, following a process, delivers on purpose a request to another team member do something. To that end, the action system is linked to the communication system and offers a player the ability to ask to do something to another player. The interaction process is similar to the asking information process.

As an illustration, an action contains associated questions (see table 13.6)

Table 13.6 – Actions are associated to questions bubbles in order to foster the player to coordinate their work

action	introduce yourself to the patient
question A	Could you do : introduce yourself to the patient ?
question B	Have you done : introduce yourself to the patient ?

13.10 Interjections

Players are allowed to send predefined phrases named 'Interjections'. Interjections should be used to express a feeling and to make them relatively free to expres themselves. Illustrating that, some interjections cited below are available:

- 'I am sick of waiting'
- 'Hurry up !! I finished'
- 'I would like to debate on the patient's identity'
- 'You are losers !'...

13.11 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 13.11). 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.

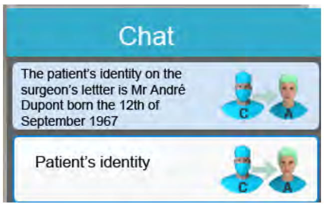


Figure 13.11 – A white bubble of information is displayed onto the chat panel and represents the communication between two characters. The thumbnails of the receiver character and the sender character are displayed. The value of information is hidden until the player click on it.

13.11.1 Working temporal continuum system

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 indications on what each character is doing and how much time it takes, should be sufficient to understand if a character is busy or not. Furthermore, listening or not an information depends on the level of attention devoted to the team and the level of concentration dedicated to the current activity. So, the graphical user interface should display an overview of what teammates are doing and how long their current tasks take.

The working temporal system is represented as a graphical panel which dynamically displays the current task of each team members.

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

- individual
- collaborative task

The teamwork activity panel shows both individual and collaborative tasks. Near the thumbnail representing the character, a progress bar makes clear how long the current action will take (Fig.13.12).

But the success of the mission doesn't only depend on the achievement of the individual technical tasks. It also depends on the dynamic exchanges of the information, on a good

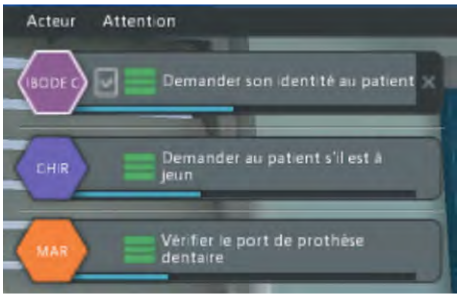


Figure 13.12 – The teamwork activity panel shows what each character is doing and how long it takes

timing for communication. All of these elements have an impact on the main common mission. The collective task need to all the members to be ready at the same time to cooperate. A default in information exchange (as a delay in information exchange, or information sent whereas the receiver is being occupied to do something else) can be a root-cause of more serious problems.

13.11.2 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. The anesthesia machine makes alerts sounds that are typical for anesthetists as in the real-life.

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

13.12 Synthesis

13.12.1 Synthèse en français

Dans ce chapitre, nous avons présenté les différents modèles et interactions qui permettent à l’équipe de communiquer de manière synchrone au sein de l’environnement virtuel. Ce système de communication innovant mis en œuvre permet aux joueurs d’échanger des informations à l’aide de bulles d’information. Ces bulles d’information mentionnent l’émetteur du message, la source sur laquelle l’information a été collectée et la valeur de l’information elle-même. Ces bulles d’informations sont représentées sous forme graphique. Elles sont manipulables par le biais d’interaction de type glisser-déposer. Elles peuvent être utilisées pour échanger une information avec un membre ciblé de l’équipe ou bien l’équipe toute entière. Des messages instantanés affichés au tour-par-tour sur les écrans de deux personnages qui communiquent assurent le suivi de la conversation. Chaque personnage possède une mémoire virtuelle dans laquelle sont stockées les informations collectées au sein de l’univers. La mémoire virtuelle contient également des bulles graphiques de questions relatives à des informations ou des tâches disponibles dans l’environnement. Ainsi, les questions peuvent être posées aux autres membres de l’équipe par simple glisser-déposer. La figure 13.13 illustre le processus de question/réponse entre deux personnages utilisant leur mémoire virtuelle.

Ce système de communication à base de bulles d’informations, d’affichage de messages instantanés, mémoire virtuelle et d’historique de conversation transpose à l’univers virtuel les régles de communications implicites évoquées dans la section 6.3.

13.12.2 Synthesis in English

In this chapter, we have presented the models and graphical interactions that enable team members to collect, exchange pieces of information, ask question… in a synchronous and dynamic way. This innovative communication system is based on graphical bubbles of information that can be found through the universe. A graphical bubble of information contains three elements: (1) the character who sends the piece of information, (2) the source of information (object, document or equipment on which the piece of information has been found), (3) the content of the piece of information.

The graphical bubbles of information can be manipulated using drag-and-drop from the character's virtual memory to inform one character or all the team about something. Instant messages are displayed in turns on the team members' screens when they exchanges pieces of information to visualize the turn-talking.

Each character gets its own virtual memory that contains piece of information which have been already collected through the universe. The virtual memory contains both bubbles of information, bubbles of questions about pieces of information that can be found or tasks that can be realized onto the universe. The figure illustrates 13.13 the communication workflow between two characters who use their virtual memory.

This innovative communication system based on graphical bubbles of information, instant messages, history chat panel and virtual memory transpose the implicit rules of communication (mentioned in section 6.3) to a virtual digital universe.

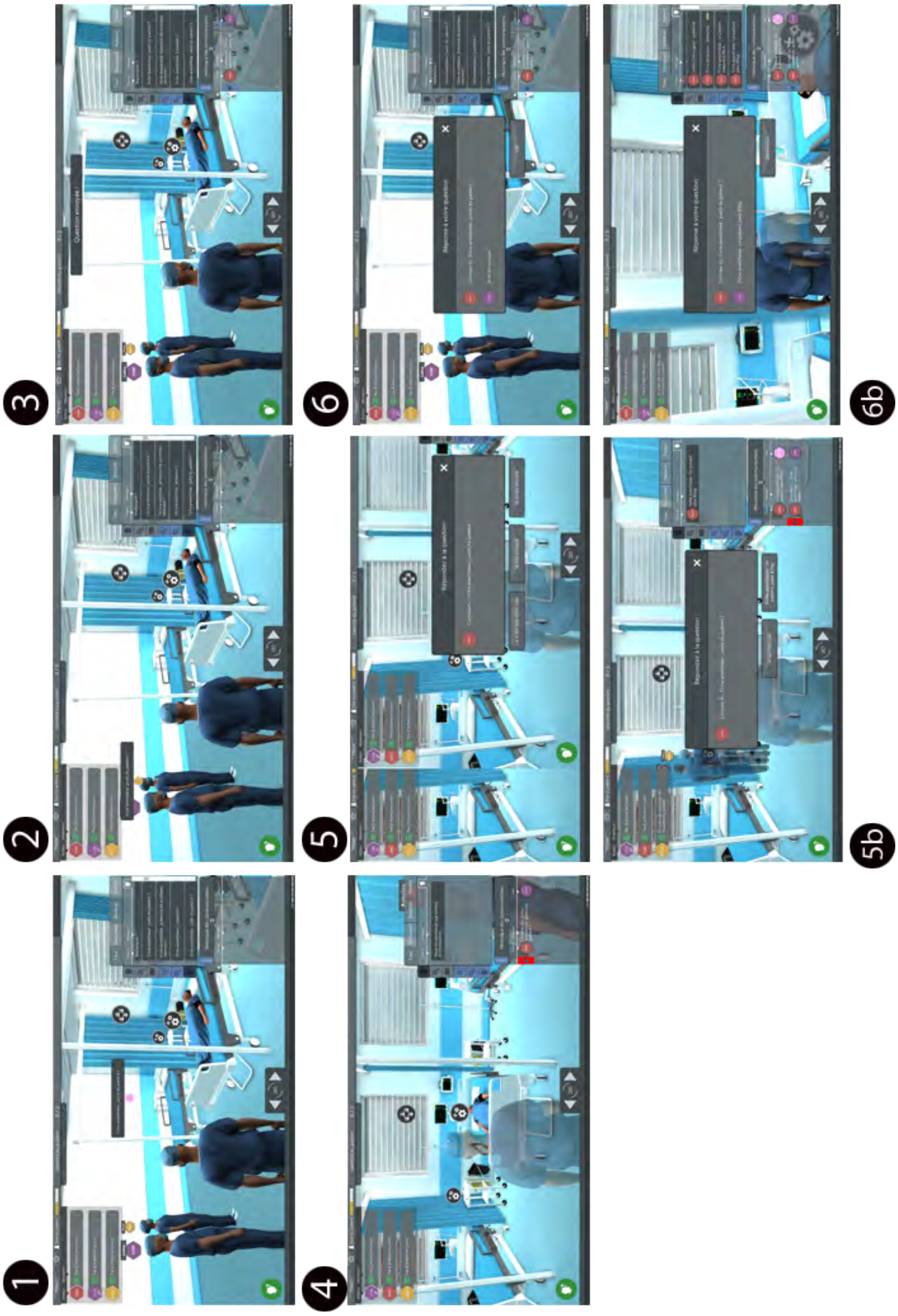


Figure 13.13 – The team members is allowed to ask and answer question. The character A chooses a question to ask in their virtual memory. The character A sends the question by dragging and dropping a bubble from their memory to the character B (1-2). A message informs the character A that their message has been sent correctly (3). The character B receives the question. A message informs the players A that the question has been memorized. Player B clicks to display the question (4-5). The character B answers the question with a generic answer or the correct piece of information that they know(5-5b). They click on the bubble-answer and a short message informs them that the answer has been sent. The character B receives the answer(6-6b).

Chapter

14

Group decision making system

14.1 Overview of the group decision making system

At this step, we need to embed in the virtual collaborative environment a group decision-making system that enables people to express their opinion, argue and make (suitable or non-suitable) decision. This system intents to show to the team the consequences and performance of their choice. Even if there is no real impact in a virtual world, they can easily imagine what could have been the consequences in a real-life situation. Secondly, it aims to train leadership of the manager and future manager, to help them identifying relevant arguments that support teammates' opinion. The system we describe is a systematization of the group decision-making process.

The dynamic context implies that each participant is individually able to update their information relative to the context dynamically. Quoting Rasmussen et Vicente [Rasmussen+1989] "In terms of design implications, these findings suggest that reliable human-system interaction will be achieved by designing interfaces which tend to minimize the potential for control interference and support recovery from errors. In other words, the focus should be on control of the effects of errors rather than on the elimination of errors per se".

The Figure 14.1 illustrates the main features of the group decision making system that have been designed here.

The collaborative universe offers to team members an opportunity to build their own representation of a current situation and probably different opinions on what to do next. As a result, 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 stage, all information argued by the participants are stored in the virtual memory of each player.

Depending on their role and the context, any player can ask for opinion team on a subject at any time. During the vote, the game is paused and no action is any longer available into the virtual environment until the final decision is validated.

14.2 A model to describe a debate

A vote is composed of a selected topic and a restricted number of available answers. The question asked is selectable in a list of limited and predetermined questions.

The model used to define a vote is presented below:

```
<vote id="v1" topic="Is the patient Mrs Caroline Laval born the 02-06-1980?"
                time="90" leader="P0" actors="P0,P1,P4" reponseDefaut="1"
                vote_discuss_max="3">
    <reponses>
      <reponse id="1" valeur="Yes"/>
      <reponse id="2" valeur="I don(t know, I need to continue to check"
                        non_reponse="true"/>
      <reponse id="3" valeur="No"/>
    </reponses>
    <infos>
      <info>piece_of_information_1</info>
      <info>piece_of_information_2</info>
      <info>piece_of_information_3</info>
      <info>piece_of_information_4</info>
      <info>piece_of_information_5</info>
    </infos>
        <solution reponseId="1">
                <infos>
                  <info>piece_of_information_3</info>
                </infos>
```

```
        </solution>
  </vote>
```

In this example, the vote topic is the patient's identity The question is : "Is the patient Mrs Caroline Laval born the 02-06-1980 ?" The available answers are : "Yes", "No", "I don't know, I need to continue the check". The vote is limited in time (the time limit is set to 90 seconds).

14.2.1 The participants

Players involved are requested to give their opinion on a selected topic. One of them is responsible for the final decision: the leader. The tag 'actors' mentions the character's role involved in the debate session.

14.2.2 The role of the leader

One of the participants has a special role: the leader. The leader is entitled with the final decision and granted the right to ignore the opinions and arguments of others. The leader is not necessary the player who triggered the vote depending on the topics and the scenario. The tag 'leader' mentions the character's role of the leader.

14.2.3 The available answers

To each question are associated several answers, which have been predefined as well as the question according to the scenario.

14.2.4 The participants' opinions

The players are free to select any answer among those available and change their mind as long as the leader has not validated a final decision. The most relevant opinion according to the pedagogical situation is mentioned inside the tag named 'solution' and the most relevant argument is also specified. It is possible for a vote to include an indecisive answer such as "Continue checking" which does not necessarily lead to an irreversible action. Such answers are allowed when designing a question. Yet, to avoid votes to be cast on the same question again and again, indecisive answers are programmed to disappear when the vote is cast for the third time, so as to ensure that a final and productive decision is made eventually. Nevertheless, the number of times that the leader can choose an indecisive issue is limited. The tag $'vote_{d}iscuss_{m}ax'$ indicates this limit.

14.2.5 The time limit

A vote is time-limited so as to avoid never-ending discussions between the team members. In the example above, the time limit has been empirically set to 90 seconds. At the end of the time limit, the leader must pick a choice and make a decision accordingly. At any time and in particular when the time is out, the leader player is responsible of the final decision.

14.2.6 Arguments

The tag 'infos' lists the available pieces of information that can be use as arguments if the participants have already collected them before the voting session.

14.3 Choosing and triggering a debate

During a typical game session, each player has a set list of tasks to accomplish as part of the usual activity, which depends on each one's occupation and work duties. These tasks imply interacting with the environment and, for them to be done right, information ought

to be collected beforehand and/or after. Yet, on several occasions in a scenario, a problem appears that must be solved collectively. In the game, there are basically two reasons for a collaborative decision to be taken: i) the team or a team member has come across an anomaly upon cross-checking information or upon receiving contradictory information, or ii) the collaborative decision is part of the safety procedure or good practice recommendations A list of predefined topics that are likely to be discussed have been established with experts during the pedagogical scenario design stage. Non-relevant topics are banned de facto from the scenario.
A collaborative decision making task can be launched by clicking on its icon like any other actions in the virtual environment.

14.4 Graphical representation and available interactions

The collaborative decision procedure is set within a contextual activity called the "voting panel" and overlaying the game window, as illustrated in Figure 14.2.

The window title (in Figure 14.2) states the question on which the team is expected to agree on a decision. Questions may take the following wordings: "Assess that patient is Mr. Dupont" (on Figure 14.2), or "Should the patient be transferred to the operating room ?"...

The participants to a vote are mentioned in the title bar by their respective colored icons.

Each answer is represented in a separate column by a label and two containers.

The upper container displays the icons of the players whose opinion leans towards this answer (see section 14.5). The lower and larger container receives the arguments in favor of this answer (see section 14.6).

Each player is also allowed to drag and drop information bubbles in provided spaces to argue their opinion. They stand for arguments or evidence to support their vote or convince the other team-mates.

14.5 Giving one's opinion

When a vote has been launched by a player, the game pauses for all of them (until the vote is ended) and the voting panel is displayed in real time on every one's screen. Each player first acknowledges the question under debate and starts expressing their opinion. This is achieved very simply by clicking on the desired answer. Immediately, the colored icon representing the player is displayed on top of the text label of the answer. The choice of each player is viewed by the others, as the operation described above is mirrored in real time on every player's screen. On GUI, when a player expresses their opinion relating to a question, the thumbnail of their character is displayed in real-time near the selected answer and indicates their choice to the other participants.

An opinion can be changed as long as the time limit has not been reached or the vote closed by the leader. We hypothesize that, depending on the – changing or stable – opinions of the other players, their expertise on the topic and their arguments, a player is likely to be influenced to change his vote just like he would do in a real life similar situation.

14.6 Arguing one's opinion

In addition to being merely expressed, an opinion can be further supported by arguments placed by players on the corresponding text repositories. Information tags in each player's virtual memory serve as arguments to defend or argue a point of view. The process of placing an argument consists in dragging and dropping an information tag from an area at the bottom of the screen (in Figure 14.2) – where all information held by the player and pertaining to the topic discussed is conveniently gathered – onto the desired repository. This way, the arguments placed on the voting panel are expected to help players influence others, or be influenced by others and change their vote accordingly. The same way he would change his opinion, a player can drop an argument should he realize it is irrelevant or simply misplaced.

On top of supporting opinions, arguments play an important role in the decision process as they help the team to build dynamically a shared representation of the situation and the circumstances under which the decision is put to the vote. In other words, we advocate that the ability for some players to convince others is a question of less importance than how accurate a representation of the situation is likely to be built, and consequently how pertinent the decision.

The designed model allows to extract a relevant set of information from the virtual memory of each character and propose them as available arguments to support an opinion. The retrieved piece of information are connected to the topic of the vote.

Players can choose not to immediately decide answering 'Continue to check' for example. Although it is possible to report the final decision, the leader must assume its responsibilities and make a real decision after a limited period. As a consequence, the system allows the leader to report three times for example their decision concerning a topic. Once that time has expired, the system does not propose a non-decision and displays only strong views on the subject.

As an illustration, table 14.1 presents the model used to represent a vote

Table 14.1 – Preselected pieces of information are associated to a vote in order to foster the player to argue and support their opinion

question to debate	Is the patient Mr. Michel Bousquet born the 12-09-1972?
leader's role in the debate	operating-nurse
participants' role	surgeon, anesthetist, anesthetist-nurse
available answer 1	Yes
available answer 1	Yes
available answer 2	Continue to check
available answer 2	No
available argument 1 (if ever collected)	The patient says their name: Michel Bousquet
available argument 2 (if ever collected)	The anesthesia file mentions Bousquet as the patient
available argument 3 (if ever collected) (if ever collected)	The surgeon their patient: Michel Bousquet
available argument 4 (if ever collected)	The surgeon's letter does not mention the name of the patient
correct answer (if the relevant argument is displayed from one participant)	yes
relevant argument	the surgeon recognize their patient.
accepted limited number of times to report the decision (as continue to check)	3

14.7 The final decision

Although the system described aims to facilitate decision-making among several users in a virtual environment, the decision is not actually made by the system. Irrespective of how much the question has been debated, and whether or not the opinions expressed are unanimous or diverging, one person only (the leader) is responsible for making a decision and taking the appropriate action. This is an important aspect of the decision-making, especially in the operating room, because whoever makes the decision will be liable for its consequences. It is therefore important that a decision will not automatically be imposed by the system on the basis of the opinions expressed, but will be left for the person in charge to take.

In practice, when the vote has ended, as the timer has reached zero, the outcome reflects the opinion of the leader. A new information tag is communicated to all the players with the final decision, and the decision is enforced automatically by the system in the game ("tick the patient's id check box on the checklist", "transfer the patient", etc). Whether or not a consensus is found, the only opinion of the leader matters. If the leader has made a decision against the other players, he/she will have to assume the consequences during the debriefing.

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.

14.8 Example of decision making in an operating room

An example of a decision made in the operating room is detailed below: A question is brought up to the other team's members (could be part of the security protocol like the time-out or before ticking an item on the WHO safety checklist, or raised by a team member to express a concern about something relative to the surgery). The question is debated. Every member of the team is free to express an opinion or none, depending on their knowledge of the situation and in all likelihood on their expertise on the matter. Opinions may be backed up by arguments. Arguments are facts pertaining to the current situation and whose knowledge is held at least by the player using it. Arguments must be collected in the environment prior to be used in a debate. Finally, based on the opinions expressed, a decision is made and acknowledged by all the participants. The system must account for each step in this process.

The communication system has been designed in such a way that information is given a tangible body in the virtual environment, taking the shape of graphical tags that can be grasped and manipulated using the mouse. Information tags represent facts that are linked to states or values of the virtual environment, like "Patient is anxious" or "Patient's name on the surgeon letter is Mr. Dupont". They are collected by each player during the game from the objects or from the patient, or received from other players as part of the player-to-player communication. A colored icon associated with each information tag indicates who is the source of the information. Information tags held by a player are grouped in a panel (as shown at the right in Figure 12.6) where they can be accessed anytime, conveniently sorted following several criteria. This panel is called the 'virtual memory' of the player since the information listed there accounts for the player's current and complete knowledge of the environment.

For instance, on Figure 14.2, the surgeon and the anesthetist are in favor of confirming the identity of the patient whereas the operating nurse, which is leader on this vote, would like to carry on the identity check. All three have argued their opinion with arguments but, the outcome is still uncertain.

14.9 Synthesis

14.9.1 Synthèse en français

Dans ce chapitre, nous avons présenté comment un débat pouvait être lancé au cours de la partie. Lors d'un débat, plus aucune activité n'est possible au sein de l'environnement virtuel, la partie est en pause tant que le débat n'est pas terminé. Un débat est défini par une question à debattre dont le sujet est préalablement défini, une liste de réponses possibles, une liste de participants dont un seul est responsable de la décision finale et une liste d'informations utilisables comme arguments au cours du débat. Lors d'un débat, chaque participant prend connaissance de la question à débattre et des opinions/alternatives possibles. Une pré-selection automatique d'informations permet d'afficher une liste d'informations susceptibles d'être en lien avec le sujet du débat. Cette liste est établie pour chacun des personnages en fonction des informations qu'il connait (celles présentes dans sa mémoire virtuelle). Les informations peuvent alors être utilisées comme arguments pour soutenir une opinion et ainsi permettre à l'équipe de se construire une représentation commune de la situation et surtout au leader de prendre une décision adaptée à la situation connue.

14.9.2 Synthesis in English

In this chapter, the group decision making system have been presented. It enable to launch a vote on a predefined topic during a game session. When a vote is launched, the game pauses for all of players (until the vote is ended) and a voting panel is displayed in real time on every one's screen. A vote is defined by a predefined topic, a set of predefined opinions/alternatives, a set of participants, a leader who is the responsible for the final decision and a set of available arguments that can be manipulated to support an alternative/opinion. During a debate, each participant acknowledges the question and the possible alternatives. The system automatically makes a pre-selection of information from the participants' virtual memory in order to help them to argue with pieces of information relating to the current topic. As a result, arguments can support each one's opinion regarding their own representation of the situation. Exchanging their point of view and supporting it with their arguments, they can build a common representation of the situation and the leader should be able to make a suitable decision according to the current situation.

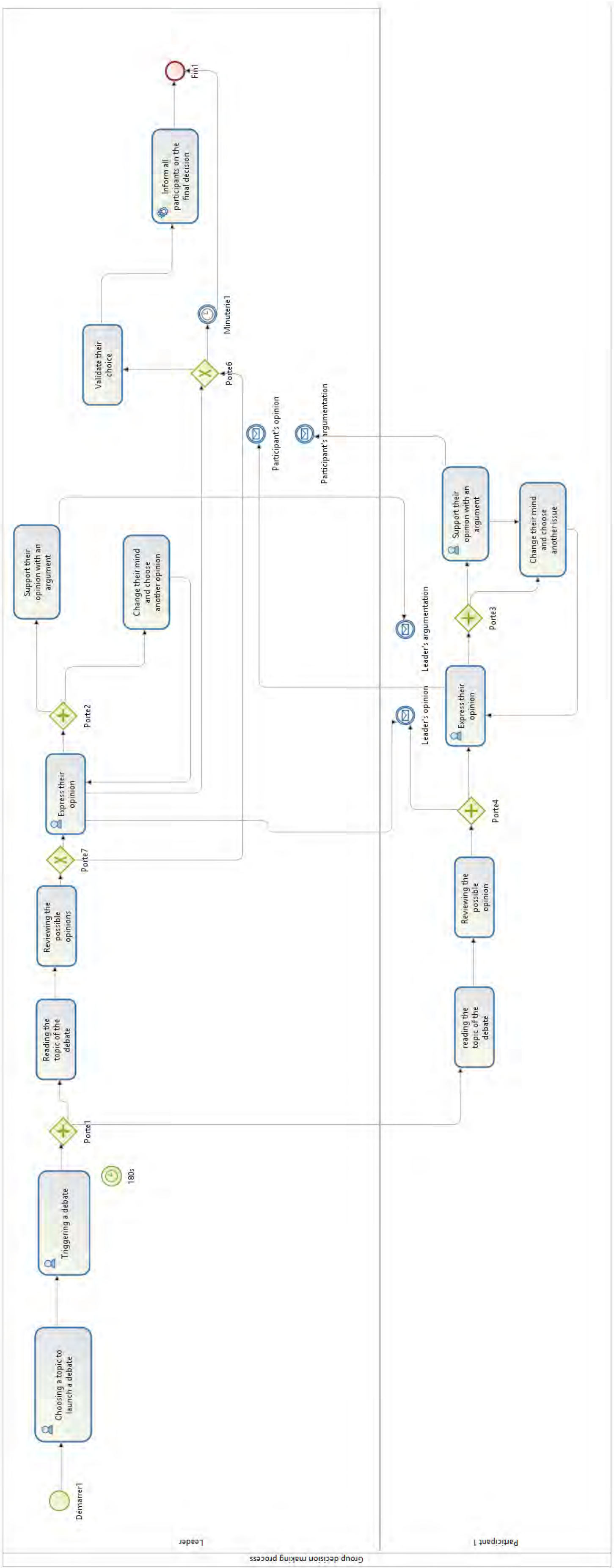


Figure 14.1 – An overview of the group decision making system.

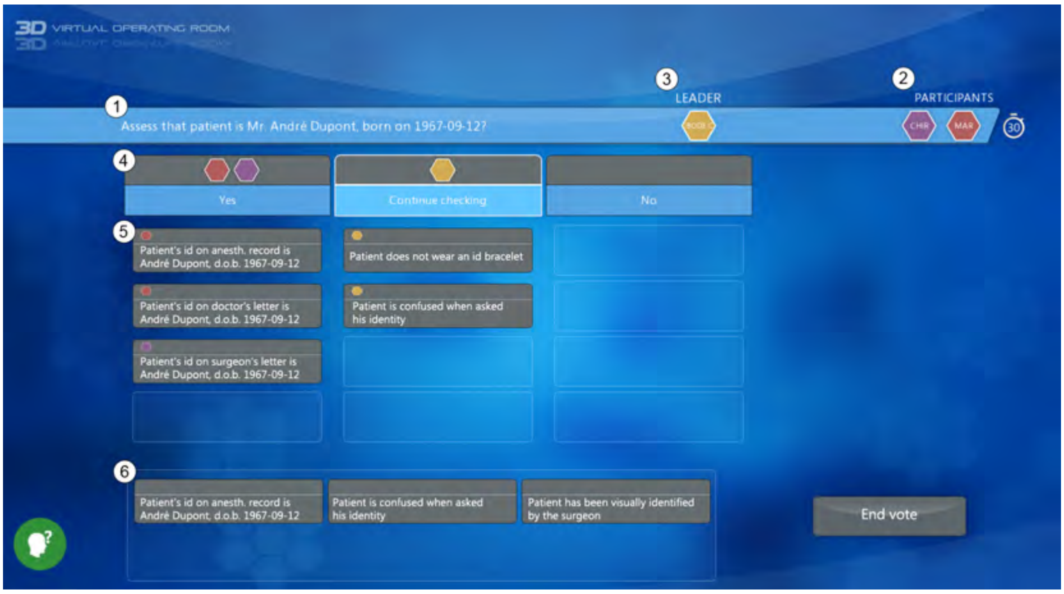


Figure 14.2 – The voting panel is an in-game activity where learners can express their opinions with the aim of reaching a consensus. Each learner expresses their opinion by clicking on one answer and argues their opinion by placing pieces of information on the corresponding areas. Arguments available in the list at the bottom of the screen depend on what information is in their possession at the moment the vote is cast. ©3D Virtual Operating Room

Chapter

15

A team tracing model: EURIKAT

Szyld and Rudolph[Szyld+2013] define debriefing in healthcare simulation as "the learning conversation that follows a simulation session. The instructor's role in providing feedback and guiding reflection is critical to ensure that reflecting on the simulation experience yields learning and growth in accordance with the stated educational goals of the session". Therefore, the trainer needs to see some cues to show an effective debriefing. The challenge here is to define a model that help to display an automatized and personalized debriefing at the end of a game session. This debriefing is supposed to help the trainees to understand their errors and the trainer to build verbally their debriefing irrespective of their professional experience. The models described in section 11.2 are used to describe different kind of objectives.

15.1 Monitoring the training activity

In real life or in training context, understanding how an adverse event has happened is crucial to improve behavior facing to a standardized or an unpredictable situation. To help practitioners and get them to commit to a rigorous approach, the National Authority for Health (HAS) recommends the ALARM (Association of Litigation And Risk Management) systemic analysis method. It proposes a systemic approach to complex systems, which includes five stages: (i) data collection, (ii) reconstituting the chronology of the event, (iii) identifying shortcomings in care (defined in relation to standards for good practices), (iv) identifying their causes (contributory and/or influential factors) and (v) proposing measures for improvement. Our model uses the ALARM method to collect, store and identify causes of success or failure, in order to display some recommendation to improve the team's performance.

At the beginning of a game session, a briefing is displayed to inform the team on the patient's pathology and the scenario's expectations. The main objectives mentioned at the briefing present a general context but the specific risks the team has to managed are not mentioned. Therefore, some objectives are displayed and others are hidden in order not to affect the behavior of the trainees.

Each training session can lead to unpredictable current status but experts know the expected outcomes and generally what are the main failures. When facing to a virtual professional situation, the application can display a part the main results based on tangible data stored during the training session.

15.2 Overview of existing models

15.2.1 Model tracing

Model tracing is a particular intelligent tutor based on the ACT-R Anderson theory [Anderson+1997][Aleven+2009]. In this case, the tutor knows the rules to perform a task and buggy rules that describe the way to fail to perform the task. In most monitoring systems based on expertise, learner activity is only compared to the regular behaviors to achieve a task, and so any deviation is considered to be an error. The tutor is supposed to alert the learner when an error is committed and guide them throw the right way.

The main inconvenient of this model is that it can not answer if the tutor does not know all the possible paths to perform a task either in a right way or not.

15.2.2 Petri Net

Petri Net has been presented in section 5.4. Thomas Benjamin et al. [Thomas+2012] propose to monitor the learner activity with an expert Petri Net where tokens represent skills. The authors consider that one of the limitation using this strategy relates to their retained hypothesis. They consider that one action matches a skill whereas most of the times, a set of sorted actions refers to a skill. As an illustration, Petri Nets have been used to describe scenarios in a serious game named "‘Play and Cure"’. It aims to train students in Faculty of Medecine to diagnose pathologies. Places and transitions have been used to represent undertaken pathologies and the possibility of the learner to confirm or cancel their suspicion. A token is placed to indicate if the answer has to be selected by the learner.

15.2.3 Bayesian Net

Bayesian Net has been presented in section 8.1.1. Bayesian Net can support diagnostic basing the analysis on plan recognition and prediction of students' actions during a training[Conati+2002].

Amokrane et al. [Amokrane+2008] developed an intelligent tutor system named HERA. Hera is supposed detect erroneous actions and guide the learner during the training providing explanations[Barot+2013]. Nevertheless, contrary to intelligent tutor based on model tracing, Hera allows the learner to make errors. To that end, they describe required procedural tasks, discrepancies and known errors. A learner model is used to keep the trace of the learner activity resulting from the analysis of his actions. An errors model relates a generic classification of errors types that may be committed by learners such as errors related to target objects (when the learner manipulates an object that is not the right one) or error role (when the learner performs a task pertaining to another role). A recognition module determines what the learner is doing inferring on an agent's task plan, based on the agent's observable actions and the agent activity model.

15.2.4 Model based on constraints

Models based on constraints [Ohlsson1994] do not focus on the sequence of actions realized by the learner. It focuses only on results comparing the expected results to the learner's results. The system checks if all the constraints have been satisfied.

Our works has been drawn from the idea that the most important for us is to compare the behaviors of teams with what is expected. To that end, a large freedom of action is given to teams members respecting the nature of their professional activities.

15.3 Different kinds of objectives

On one hand, in order to assess the performance of the students, the model embeds a set of metrics to measure how well the standard procedures are applied and how the team of students reacts when they are facing to an unpredictable situation. On the other hand, others objectives are used to divide the scenario into small steps and inform the students on their progress during the game session. As a result, different types of objectives compose a game scenario:

- step objectives to inform on the level of progression in the scenario [visible]
- educational objectives that are not visible to the trainees but are monitored by the game [invisible]. There are two sub-types of these:
  - objectives of success (expected outcomes) to inform on what was correct to reduce risks
  - objectives of cause of failure (predictable failures) to inform on what increased a particular risk

Educational objectives have to be designed as part of the scenario and must be checked in real time by the game. This allows to provide an automatized and personalized debriefing based on the activity during the game session. Nevertheless the application needs to be able to understand what is the main goal and how it can be evaluated. Most of the time, applications are not able to evaluate events which can not be listened by the game. So, all the macro-objectives have to be composed of micro elements that can be listened and captured on the GUI. Then, all the micro elements need to be associated with a particular grammar to construct macro-objectives.

15.4 Script objectives

The script objectives are defined for two main reasons. The first one is very simple: the learners need to know what to do and be inform on their progress during the scenario. The script objectives help to rhythm the party. The second reason is that dividing the scenario into smaller period makes easier to reduce the number of available actions and pieces of information on each step.

15.4.1 Objective cast 'Game Over'

The 'Game over' objectives help to define the different predictable ways to end the party.

15.4.2 Objective cast 'Step'

The step objective helps to divide the professional activity into smaller period in order to minimize the number of available actions on the scene. Contrary to educational objectives, they are visible by the learners.

```
<steps>

<step id="E00" description="" leader="P3" >
        <objectif id="1_01"
        description="Check the patient's position on the surgery table"
        objectifReference="Obj_STEP_01" acteurs="*"/>

        <objectif id="1_02" description="Check the patient's skin"
        objectifReference="Obj_STEP_E02" acteurs="*"/>
</step>

<step id="E01" description="Induction" leader="P1" >
        <objectif id="2_01" description="Anesthtetize the patient"
        objectifReference="Obj_STEP_03" acteurs="*"/>

        <objectif id="2_02" description="Install the tube"
        objectifReference="Obj_STEP_04" acteurs="*"/>
</step>

</steps>
```

15.5 Educational objectives

The educational objectives are objectives that are monitoring all along the game session by the game engine. Contrary to 'step objectives', they are hidden to the learners. They constitute the secret part of the scenario. They are composed of 'success' objectives and 'error' objectives. The "'error objective"' i.e., objective that is not correct but need to be monitored. The success objective defines a right way to achieve a task, apply a safety procedure or adjust a procedure to the current context. The "error objective" concept helps to define predictable error or predictable wrong behavior regardless the kind of task to achieve: contextual action, communication, decision making.

The concept of 'buggy behavior' is associated to the wrong way to achieve a task even tough the task has been achieve. For example, let's consider the situation where someone is very hungry and needs food. The main objective is: feed himself One behavior could be: (1) go to a restaurant, (2) have a look on the menus (3) check the price, (4) order (5) eat (6) pay the bill and (7) leave the restaurant
Another one could be : (1) go to a restaurant, (2) order (3) eat (4) pray to be able to pay

the bill
Another one could be: (1) go to the restaurant, (2) order, (3) eat, (4) leave the restaurant
There are multiple ways to eat without any constraints. Nevertheless, some behaviors presents more or less advantages considering constraints such as saving money to prevent the risk of unexpected expenses or risk of jail.

A "buggy behavior" is associated here with a risk to prevent in a scenario.

15.6 Unit element

To define educational objectives or step objectives, some basic unit elements have to be defined.

As an illustration, the events in Table 15.1 are events that can be observed and automatically captured by the game during the game session. Unit elements are actions, information acquisition or transmission, discussion and decision making. They can be considered as micro-objectives and therefore they must be associated in order to construct more meaningful game objectives.

Table 15.1 – Element types necessary for defining an objective

Element type	Example(s)
action	Someone makes a contextual action.
	A team member writes something on a document
communication	Someone sends a piece of information to someone else.
	Someone collects a piece of information 'anomaly'.
	The team initiates a collaborative discussion.
	Someone argues a relevant argument.
	Someone asks a question to another member.
inspection	Someone reads an information on a document.
decision	The team makes a decision on a topic.

The next sections describe a set of unit elements that is used to define complex objectives.

15.6.1 Objective cast 'Info'

An objective 'Info' supports to check if a character's role knows a particular piece of information.

```
        <objectif id="Obj_1" type="INFO"
        description="" information="identiteBracelet_patient"
        acteurs="RespChecklist" />
```

15.6.2 Objective cast 'Action'

This kind of objective help to control if an action has been realized or not. The following example illustrates how to use it.

```
<objectif id="Obj_2" type="ACTION"
        description="protect the natural jungle with human-free area."
        action="action_02" actors="2" />
```

15.6.3 Objective cast 'Vote'

An Objective named 'Vote Objective' supports to define a result obtained from the group decision making system. It allows to check the final decision to move forward throw the scenario.

```
<objectif id="Obj_3" type="DECISION"
description=" Are the panthers in danger ?"  vote="v1" reponses="1" />
```

15.6.4 Objective cast 'VAR'

An objective cast 'Var' define the expected value set on a particular object.

15.7 A specific grammar to build complex objectives

Complex objectives are constructed by the tree-like association of unit elements. Operator nodes are introduced in the pedagogical description grammar in order to do so. Table 15.3 lists the available operators. Owing to the tree-like recursive description model, the expressiveness is potentially unlimited, although in practice only a few layers are necessary for a complex objective to be defined (see Figure 15.1). The ORDER operator allows designers to define an objective with a set of basic elements that should to be done in a specific order. For example, to test 'infectious outcome', the application needs to know if the player first washes their hands, then puts their gloves and injects drugs. If the user first injects drugs then puts their gloves, the infectious risk is very high. So the application needs to store the chronology of what happened. The order between actions and communication is also important especially for the surgical security checklist. Before ticking the checklist to confirm the patient's identity, the checklist leader has to collect all the information about the patient's identity from all the team members. The operators help designers to combine different objectives to build new complex objective.

Table 15.2 – A grammar to combine objectives

operator	usage	expression
OR	objA OR objB	'objA' or 'objB' has to be fulfilled
AND	objA AND objB	'objA' and 'objB' has both to be fulfilled
NOT	NOT(objA)	the opposite of objective 'objA' has to be fulfilled.
AT LEAST	AT LEAST ((objA, objB,...), x)	at least x objectives among (objA, objB,...) has to be fulfilled
ORDER	ORDER(objA, objB,...)	the list (objA, objB,...) has to be reached in the specific order

Table 15.3 – Operators are defined to describe and combine objectives

Operator	Expression
OR	At least one sub-objective must be fulfilled
AND	All the sub-objectives must be fulfilled
NOT	the opposite of the objective has to be fulfilled.
AT LEAST	at least x objectives among the sub-objectives must be fulfilled
ORDER	All the sub-objectives must be fulfilled, and in a specific order

```
        <objectif id="Obj_ERROR_45" type="COMPOSE"
        description="The checklist manager confirmed the patient’s operating
        site whereas he did not know anything about the operating site.">
  <operateur type="ET">
  <operateur type="ORDRE">
                <action id="ActionOrdreCkl2" acteurs="" />
                <action id="ActionOrdre_02" acteurs="" />
        </operateur>
                <objectif id="ObjEndGame_AutoGenerated" />
        </operateur>
        </objectif>
```

15.8 Buggy behavior: identifying errors and defining a predictable error as an outcome

The same model is used for representing the expected outcomes of the game as well as the unexpected, yet predictable, errors. For example, the checklist manager ticks the box to confirm the patient's identity whereas they did not make a cross-control of information on patient's identity. They have to check from the patient their identity and check on patient record if the same identity is present on any document. The main regular error consists in confirming the patient's identity without any cross-control. Therefore, the same actions can be bound to a success objective as well as a failure. The success objective consists in i) reading or collecting patient's identity information from the others on any documents in the medical record, ii) discussing and making a decision to confirm the patient's identity and then iii) ticking the box on the checklist to confirm the patient's identity. Ticking the same checkbox without any prior cross-control or collaborative discussion is considered as a failure in the procedure and therefore a failure objective.

15.9 How does it work ?

All the objectives relating to a scenario (expected behavior, success, failure, optimized behavior, buggy behavior, script objective and level of progression) are likely to be presented in a large variety of tree-like structures where nodes represent objectives and leafs represent expected action, communication and decision. At the beginning, the application initializes all objectives with a Boolean value “false”. While students interact with the virtual scene, the 'Educational Objectives Monitoring' module listens every events and checks if some objectives are fulfilled either by the individuals or by the team. When an objective is reached, it converts their value to “true”. None objective can move to "‘true"’ if it has been set to false before. Step by step, objectives are reached or not. At the end of the training session, the application is able to display the main outcomes.

This primary objective overlaps with educational objectives linked to the current damaged situation. The schema in Figure 15.1 exemplifies an educational macro-objective that combines different expected unit elements associated with operators.

15.10 Synthesis

15.10.1 Synthèse en français

Dans ce chapitre, nous avons présenté un modèle inspiré des modèles à base de contraintes qui permet de décrire différents types d'objectifs associés à un scénario i.e. les objectifs scénaristiques (qui définissent les étapes d'avancement), les fins de parties, les objectifs de mission, les objectifs pédagogiques incluant les tâches comme l'action contextuelle, la communication ou encore la prise de décision. Les comportements individuel et collectif, attendues, optimisés, erronnés ou inadaptées peuvent être décrits avec ce modèle. Le modèle nommé EURIKAT permet de décrire des objectifs simples ou complexes sous forme de structure arborescente à l'aide d'opérateurs. Au début d'une partie, tous les objectifs sont initialisés avec une valeur booléenne à Faux i.e. aucun objectif n'est réalisé. Au fur et à mesure de l'activité, les objectifs peuvent prendre la valeur 'VRAI' mais ne pourront plus ensuite revenir à leur valeur initiale. A l'issu d'une partie, il est alors possible de connaitre le niveau d'achevement d'une mission ou bien d'objectifs pédagogiques précis.

15.10.2 Synthesis in English

In this chapter, a team tracing model has been presented. Our works has been drawn from the idea that the most important for us is to compare the behaviors of teams with what is expected. To that end, a large freedom of action is given to teams members respecting the nature of their professional activities. The model EURIKAT enables to describe objectives that are linked to the scenario itself such as script objective or game over and educational objectives (both success behaviors and buggy behaviors) that include task achievement, contextual action, communication and decision making. This model allows to describe both simple unit objective and complex objective that results from a combination of unit objective. A tree-like structure where node are operators and leaf are objective help to describe such complex objective. At the beginning of a game session, all the objectives are initialized with the value 'False' i.e. none of them is achieve. Progressively, as times goes by and students interact with the environment, the value of an objective can move to 'True' but they will never turn to 'False' again. At the end of a game session, the level of achievement of a task, a mission or an educational objective is known.

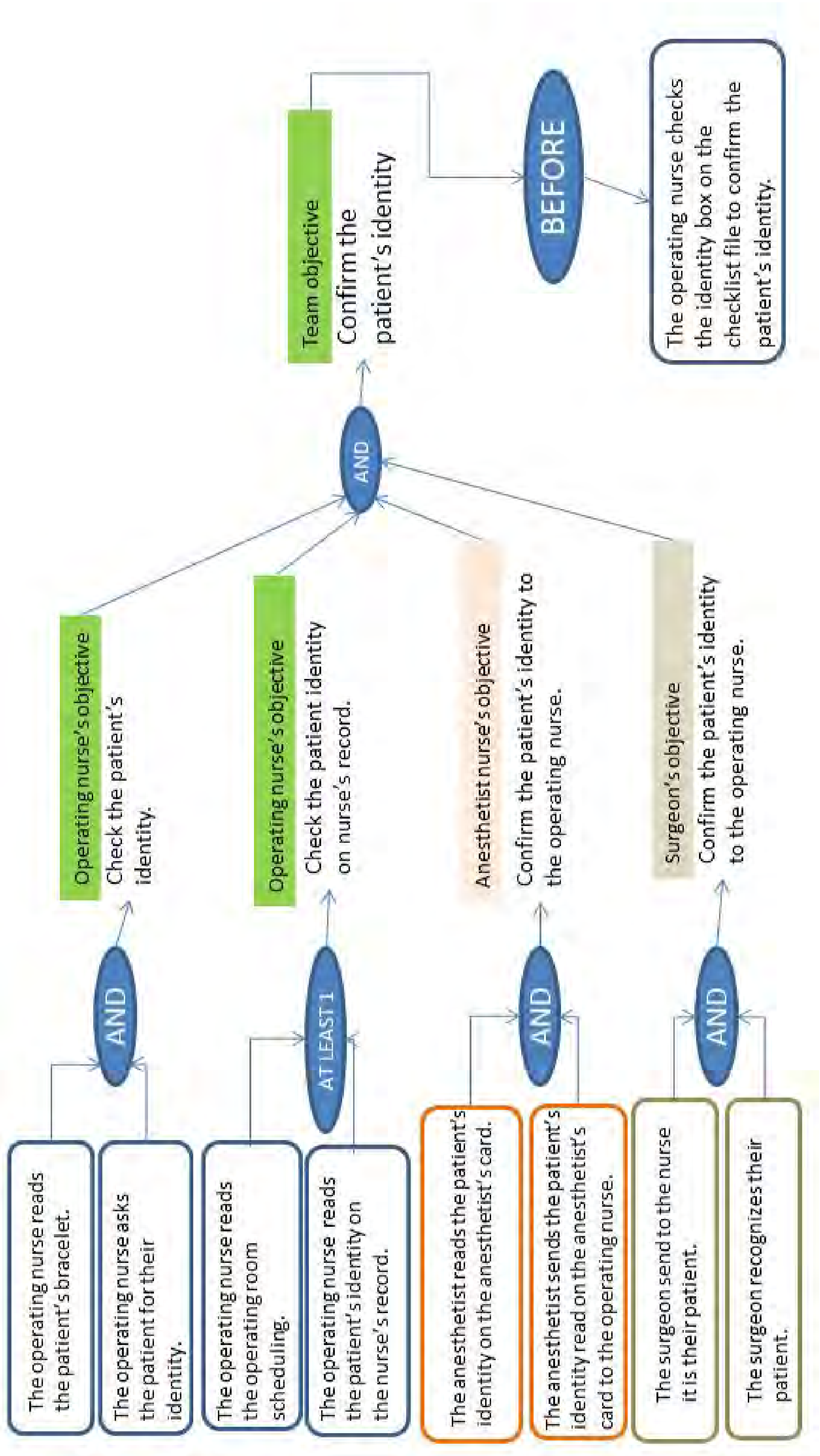


Figure 15.1 – The educational objectives can be represented in a tree-like structure where nodes represent objectives and leafs represent action or communication.

Chapter

16

Particular Risk Management Debriefing

The question of debriefing at training sessions remains essential as it is of crucial interest in the learning process. The aim of the present chapter is first of all to offer a structured method for collaborative debriefing that is both reproducible and whose quality remains independent of the trainer's level of expertise. This leads on to investigating how this method can be introduced into a serious game for training in order to organize semi-automated and customized debriefing for each team of participants.

The first step will involve studying how professionals analyze a real and serious adverse event a posteriori and how the trainers conduct debriefing of the simulation session (by means real place with real equipment in a fictional context).

A structured, standardized and semi-automatic, collaborative debriefing method will then be proposed to address the adverse event, near-miss or accident. The model described above enables to monitor the team activity in details. As a result, a standardized, personalized debriefing can be automatically displayed.

The point is how to present the debriefing at the end of a game session. The second part of this chapter will be devoted to the collaborative virtual environment whose objective is to provide training in the prevention and management of serious, adverse events involving inter-professional communication in fictional, but realistic at-risk situations. It will be seen how the method proposed in the first part can be usefully brought into this facility.

16.1 Debriefing process in a training context

Any training includes a succession of three stages: 1) a briefing, during which it is explained how the session will be run together with an introduction to the training objectives; 2) the activity itself (or game stage) during which the participants play out the scenario specially designed to work to the teaching objectives relating to the established curriculum; 3) the debriefing.

Conventionally, the briefing precedes the training session, while the debriefing follows immediately after it. The debriefing provides an opportunity for an interactive and participatory exchange of views during which the trainer/instructor intervenes actively to dissect the strategy implemented by the students/trainees to handle the proposed learning situation. A debriefing generally involves 3 stages [Szyld+2013]: a stage where the players can express themselves and share in their reactions, a stage for analysis of the different phases in the game, and finally a summing up that highlights both the positive and negative aspects in individual and collective performance. The final goal is to reinforce positive actions and behaviors and seek to mitigate those that are not so effective. The instructor then takes on the role of an 'expert' student, a facilitator for learning. They analyze and guide thinking about the activity during stage 2 after the event while also nurturing a climate of mutual trust. During this stage, the students/trainees adopt a position of reflective observation as a necessary and prior stage to time being devoted to conceptualization [Kolb1984] that may then be deployed when confronting similar situations in the future [Grant+1992]. Despite the major role the debriefing plays in the learning process, there are few recommendations to assist the trainer in conducting a structured debriefing. The contents and methods used during the debriefing vary according to the level of expertise of the instructor/trainer, institutional and individual choices, and the teaching objectives targeted and selected in the curriculum or the baseline for skills [Savoldelli+2013].

Studies show that the debriefing appears to be more effective when conducted immediately after the simulation [Walsh+2009]. The time devoted to the debriefing in medical training sessions is generally two to three times longer than that taken by the session of activity. This is in stark contrast to the shorter times for debriefing in other fields as in aeronautics and the nuclear industry [Savoldelli+2013]. The question of how a structured debriefing is to be organized is probably the reason for this contrast.

The question of debriefing in the context of socio-technical and dynamic system is a delicate one as it relates to the complexity of the system. Indeed, teamwork in the operating room cannot be summarized as the straightforward coexistence between technically competent individuals. As an illustration, the operating theater can be considered to be a complex system since it functions in a dynamic and uncertain environment, with the professionals concerned maintaining among themselves relations that can be both hierarchical and complementary around a shared goal of dispensing optimum care for the person being operated on. Each surgical team and each of its members have specific skills and knowledge. The special skills and the highest level of expertise of each of the individual team members do not, however, vouchsafe the team's best results [Burke+2004]. The debriefing should take into account both each member's capabilities in carrying out their tasks and the ability of the team to ensure precise co-ordination.

The question of debriefing independently of any instructor within the context of the operating theater has also been addressed. Indeed, a recent study was conducted with 120 participants (interns in surgery, anesthesia, nursing staff, etc.) in the operating theater. Two team debriefing methods were used during extremely realistic sessions simulating a critical interoperative situation, one involving auto-debriefing without an instructor and the other conventional debriefing accompanied by an instructor. The study shows that the team-based debriefing without an instructor is effective [Boet+2013].

The question of how a structured debriefing is to be organized thus arises. It is not specific to learning methods (simulation or video-game style scenarii). However, what is required is a structured methodology where a semi-automated debriefing is to be offered to a team of participants.

16.2 From real serious adverse event debriefing to fictional serious adverse event debriefing

The players have to apply both technical knowledge and non-technical skills in order to make the best decisions. The competences called on during these simulations of real-life situations relate to task management, communication, team work, leadership, awareness of the situation and decision-making. Whatever the field, a successful team is much more than a sum of individuals who are each experts in their own particular field [Burke+2004] Among the characteristics that are absolutely essential to constitute a good team there is the knowledge and understanding of each person's role, the choice of a leader (who may change according to the context or the type of decision to be made) and sharing of information so as to ensure there is a common view of the situation. In such a context, where information sharing is so essential, difficulties encountered by teams lacking such a multidisciplinary culture and/or who do not partake of such an approach on a regular basis can readily lead to an adverse event.

As a result, analysis of an adverse event within such a system cannot be restricted to identifying technical and/or individual malfunctions [Reason2000]. On the contrary, there is a need to understand how the complex system works wherein the sharing of information, communication and team work are essential elements to vouchsafe good performance.

16.3 An innovative method to display debriefing for risk management

To our knowledge, there are currently very few digital learning games available for the team training in the area of risk management. As a result, the issue relating to modeling of a multi-player debriefing has not been addressed.

With the virtual collaborative environment, the participants are put in a situation liable to lead them to a fictional adverse event. This stage occurs during the game time and corresponds to the reference professional situation prior to the emergence of the adverse event. The debriefing stage within the game meanwhile simulates a real-life accident analysis meeting.

The particular case of risk management training implies to examine in details what is expected after a training session. To that end, we study how experts analyze accidents by using systemic analysis method (see sections 10.4.1 10.4.2). During the analysis, experts (because they are experts) analyze the chain of events before the incident and identify every causal events or deviant events. This stage is called 'factual analysis. Then, they must identify the root-causes of the accident during the systemic analysis stage. Regarding a classification of predefined root-causes, they must identify what events might have had an influence on the accident occurrence.

If we compare the expert analysis meeting to a training debriefing on risk management, there are many similarities. In case of accident, both experts and students must analyze why it happened. In case of training session, students are not able to build a chronology of what happened, identify deviant events, errors or wrong behavior they made during the game session. As a result, the game engine (as we saw in section 15) analyzes the chain of events and provides them feedback on what should have been done comparing to what have been done. Finally, the game engine is able to automate and personalize a factual analysis on real-time at the end of a training session whereas in real-life, experts do it. Nevertheless, as the experts in real-life, student involved in a risk management training session can identify root-causes of near-miss among a list of predefined items. This step should be instructive as it should help them to individually express their point of view about the team performance. The game engine can compare their outcomes with their point of view.

We propose to structure the debriefing by adapting an accident analysis method. The aim here is to get the participants to observe the systemic nature of the accident's emergence and the possibility of implementing individual improvement measures to the benefit of the team as a whole. The method involves conducting a debriefing in two stages immediately after the game session. First of all, the participant will identify the underlying causes having led, in their view, to the incident. The first stage of the debriefing will provide an opportunity for each of the team members to individually assess the situation by conducting a guided systemic analysis. That analysis comes in the form of a series of questionnaires aiming to present the situation from different perspectives, enabling each of the players to step back from the fictional situation that has just been lived out to attain a broader view. According to the ALARM methodology in the field of health, the points of view presented are classified into 7 categories: patient, players, teams, tasks, environment, institution and organization.

Within the virtual collaborative environment, only points of view relating to the underlying causes behind the scenarii are suggested to the players, i.e. the players themselves, team, tasks and the environment.

Following on from this, the participant is confronted with the results of an automated factual analysis of the actions undertaken during the game sequence. The model EURIKAT (that has been presented in chapter 15) enables us to provide such a factual analysis debriefing. This factual analysis confronts the underlying causes identified during systemic analysis with the (individual and collective) health care failings actually observed by the machine, i.e. malfunction, absence of care, partial application of procedures, inadequate sharing of information, haphazard decision-making, etc.

In the factual analysis, objectives have been grouped by category in order to present different approaches concerning the teamwork. As an illustration, objectives can be grouped either by risk or by skills. . .

The figure illustrates 16.1 the second step of the debriefing.

These successive appraisals work towards relating awareness of the situation as experienced with the solutions to be implemented to remedy matters. This approach tends to strengthen the clear sense of having acquired the skills needed to maintain confidence while also alleviating the feeling of individual guilt.

Each participant has their own perception of the situation in relation to the information they dispose of. This self-assessment after the event allows the players to globally assess the complexity of the situation having led to the major adverse event. Such self-evaluation is then correlated with an automated factual analysis where each person's particular deviations are pinpointed. The underlying causes of the malfunction, as associated with health care failings, underscore the systemic nature of the way the incident arose. It is this two-way process of thinking between the real situation and the virtual situation followed by reflective analysis on the actions performed or to be performed that lead the participants to develop and enrich their experience and competences. Indeed, even though the situation is simulated, the experience as lived out is quite real and can thus be transposed into the professional context.

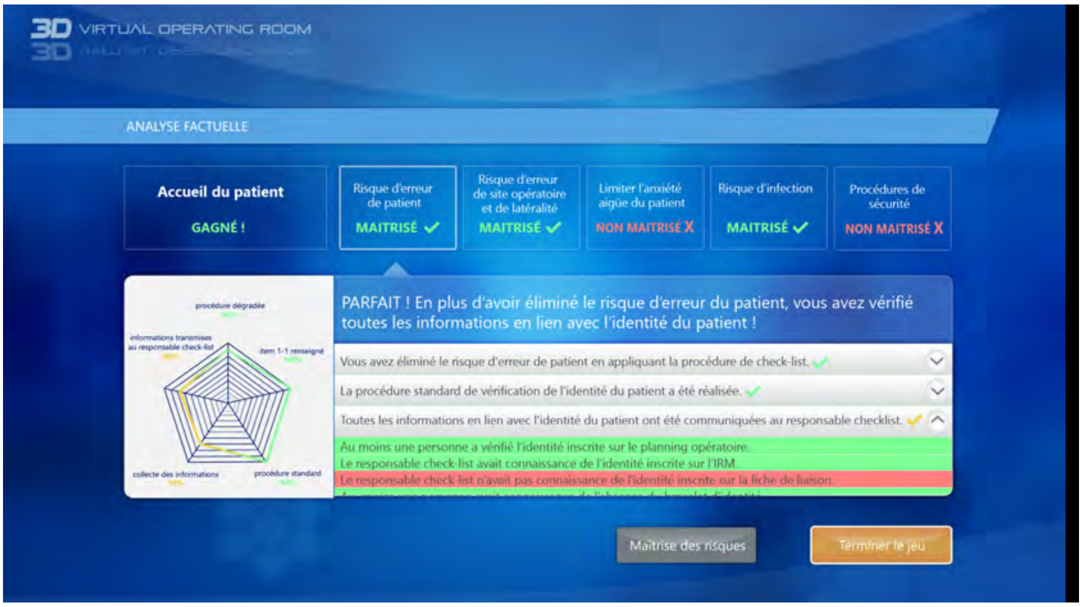


Figure 16.1 – The debriefing is composed of two steps. The second one provides an automatized and personalized factual analysis i.e. the game engine displays personalized feedback throw advices or recommendations regarding to the expected behaviors.Educational objectives and risks have been grouped by category

Figure 16.2 – The debriefing is composed of two steps. In the first step, students were individually asked what risks they think they manage during the game session. Then, the game engine displays a synchronized and share view of individual answers. Their individual point of view are represented and compared to the real team performance.

16.4 Synthesis

16.4.1 Synthèse en français

Dans ce chapitre, nous avons présenté une méthode originale et innovante pour organiser le debriefing à l'issue d'une séance de formation à la gestion des risques. Cette méthode s'inspire en partie des pratiques professionnelles en matière d'analyse a posteriori d'incidents. Cette analyse s'appuie en réalité sur des méthodes d'analyses systèmiques et factuelles. Dans le contexte de la formation, la méthode que nous proposons consiste dans un premier temps à demander aux joueurs de s'auto-évaluer individuellement en précisant les points qui selon eux ont pu conduire à l'incident virtuel qu'ils ont pu provoqué ou bien à définir quel a été leur niveau de maitrise des risques, puis dans un second temps, leur sont présentés les résultats de l'analyse comparée de leur activité avec leurs points de vue sur une interface partagée par l'ensemble des joueurs de l'équipe. Dans un troisième temps, les résultats de l'analyse factuelle réalisée de manière automatique par le moteur de jeu leur sont présentés sous forme de rapport de synthèse graphique. Ce dernier contient pour chaque risque les actions à réaliser pour améliorer leurs perfomances en fonction des tâches qu'ils ont réalisées ou non, des processus de sécurité appliqués ou non...

16.4.2 Synthesis in English

Through the present chapter, an innovative method has been proposed to organize a collaborative debriefing within the scope of training in risk management. This method relies both on the professional practices recommended by the French National Authority for Health and on systemic analysis methods that are used after an occurrence of adverse event. This chapter shows how this method has been adapted to provide a customized and reproducible debriefing which quality is constant and independent of the trainer's level of expertise. In the context of risk management training, the method we propose consists in three steps. The first step consists in asking players to self-assess identifying the root cause of the virtual incident they could have provoked or determine their grade of risks management if they did not provoke a virtual adverse event. Secondly, their individual opinions are compared with their activity results and displayed on a team shared screen. Thirdly, they receive the contents of the activity report that mentions what was good and what would be done to succeed. This report is automatically calculated from the current team activity.

Part IV

Experiments

Chapter

17

The training scenarios

Less than ten scenarios have been designed using the method described in chapters 10 and 11. Training sessions have been organized using the learning game environment, which offers a library composed of standardized and critical scenarios. The experiments were carried out with the help of medical trainers and anesthetist-nurse trainers at the University Hospital of Toulouse. They aim to control how the students apply safety recommendations in real-life like situations. Lessons had already been delivered to the students on said topics prior to the experimentation and all the students had already worked in a real operating room during a professional internship.

The educational content used to apply the method is based on real adverse events. These adverse events have common characteristics: a communication or decision making defaults have been identified as a contributing factor.

The training scenarios used for these experiments focused on the same period of a surgery. The first training scenario is based on a standardized and perfect situation (see section 10.4). The second one has been designed representing an irregular situation (see section 10.4).

Both, they focus 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 [Patient Safety2009] in all operative procedures. In a lot of studies, wrong surgery site, wrong patient events or wrong procedure are often reported [Authority2012; Seiden+2006]. But they appeared in 1,7 to 3,6 events among 100 000 operations [Seiden+2006].

These scenarios were designed to train people on the patient security checklist "safety checklist in the operating room" [Busemann+2012] 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 'irregular' scenario involves three characters: a surgeon (chir), an anesthetist or anesthetist nurse (mar) and an operating room nurse (ibode) whereas the 'standardized' scenario involves two characters: an operating nurse (ibode) and an anesthetist (mar). In the 'irregular' 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 surgical bed, prepare the anesthesia material. . . (see table 17.1)

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 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 three identified topics : patient's identity, patient's operating site, move the patient from the operating reception room to the operating room.

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 17.2). For example: bracelet unreadable, patient can't say anything because of his disease, document unfulfilled, different operating sites written on different documents...

In the 'irregular' 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 fulfill, the risks increase until the training session was stopped (see Fig. 17.1). This primary objective overlap with educational objectives linked to the current damaged situation. The scheme 17.1 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.

Table 17.1 – 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

Table 17.2 – 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

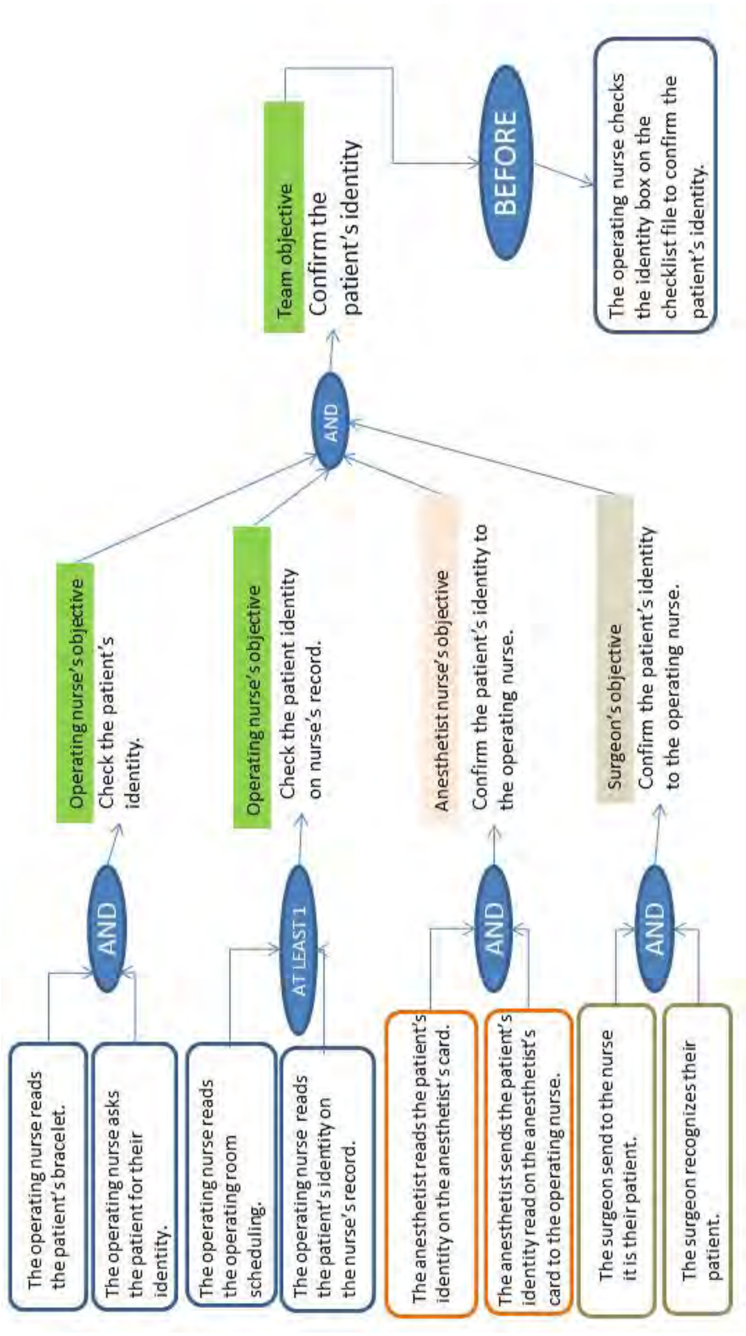


Figure 17.1 – The educational objectives can be represented in a tree-like structure where nodes represent objectives and leafs represent action or communication.

Chapter

18

Experiments to assess the communication system

18.1 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 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

Figure 18.1 – 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.

pair-up so that each team would be composed of 3 teams of two students (see Fig. 18.1). 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 anesthetist's 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.

In the following sections (section 18.2 and section 18.3), the analysis are conducted according to two 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.

18.2 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 time-line 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.

18.2.1 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 18.2 and 18.3) 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 two 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.

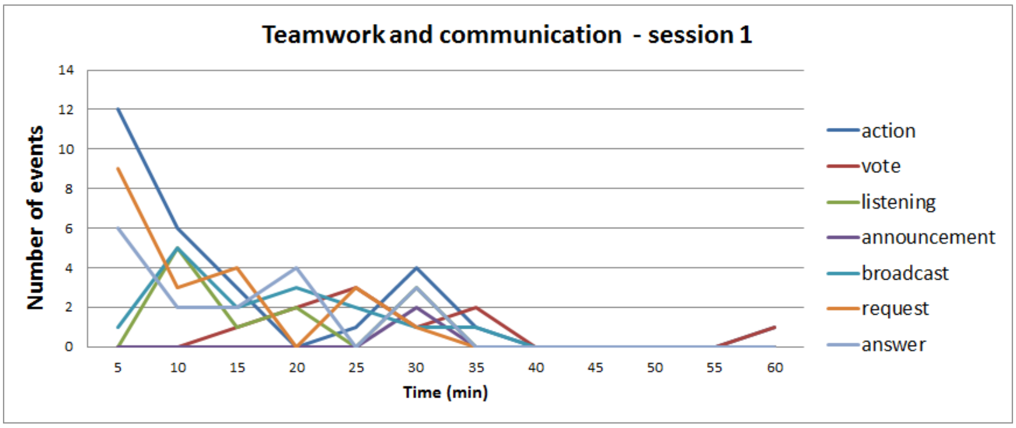


Figure 18.2 – Global activity grouped by features - session 1.

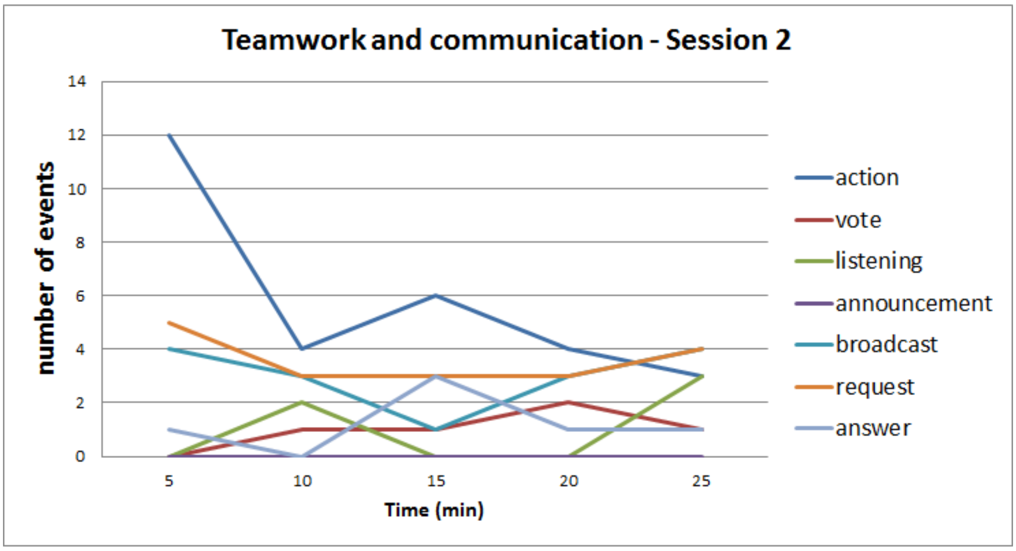


Figure 18.3 – Global activity grouped by features - session 2.

Graphic on figure 18.4 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.18.5 and graph.18.6) 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 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 .

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

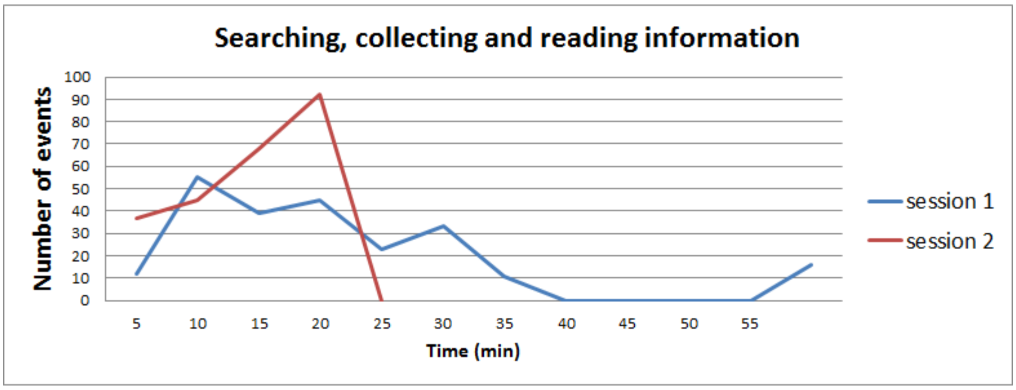


Figure 18.4 – comparing global seeking activity between session 1 and session 2.

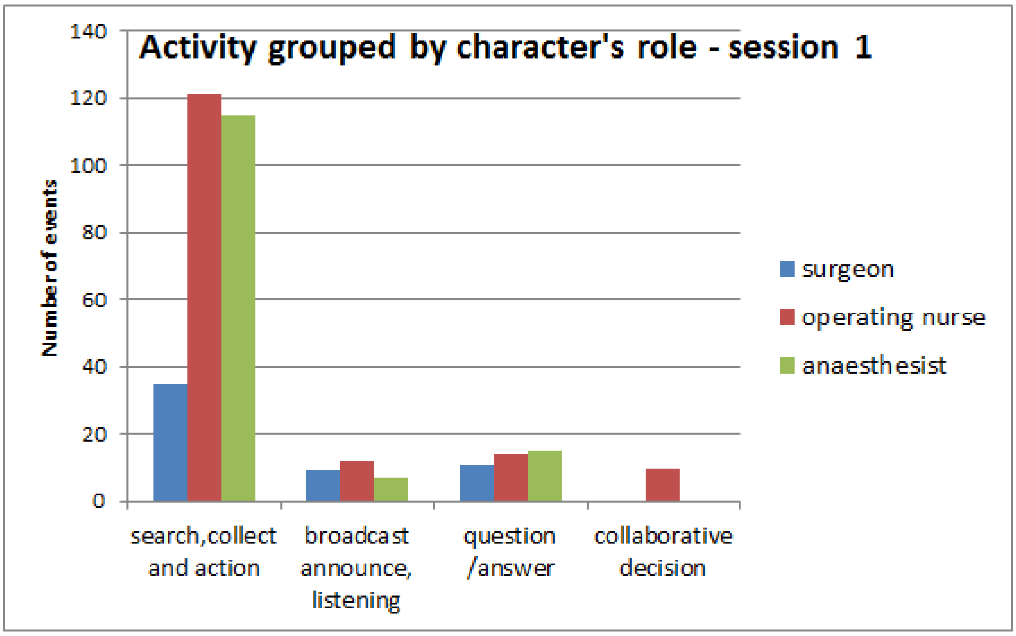


Figure 18.5 – Global activity during game grouped by character's role - session 1.

have temporarily lost the track of the scenario. This problem is 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.

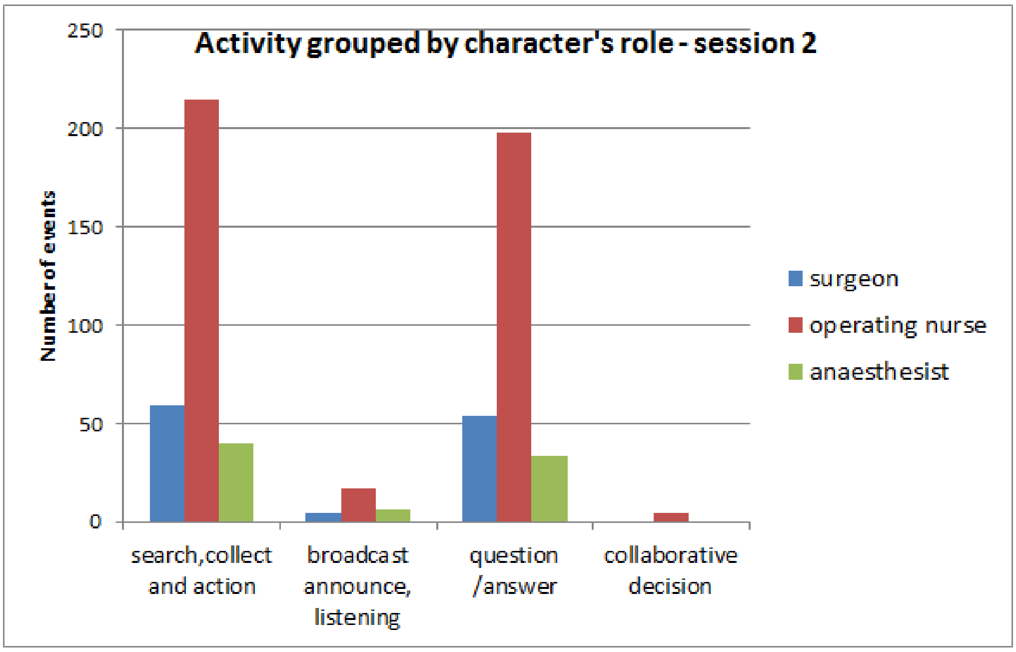


Figure 18.6 – Global activity during game grouped by character's role - session 2.

18.2.2 Feature "collect information on documents" analysis

Histograms on figures 18.7 and 18.8 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 18.7 and 18.8 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.

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

The graphical data 18.9 illustrates a global view of the activity according to broadcast, listen and announce information to the other characters.

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.

18.2.4 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.

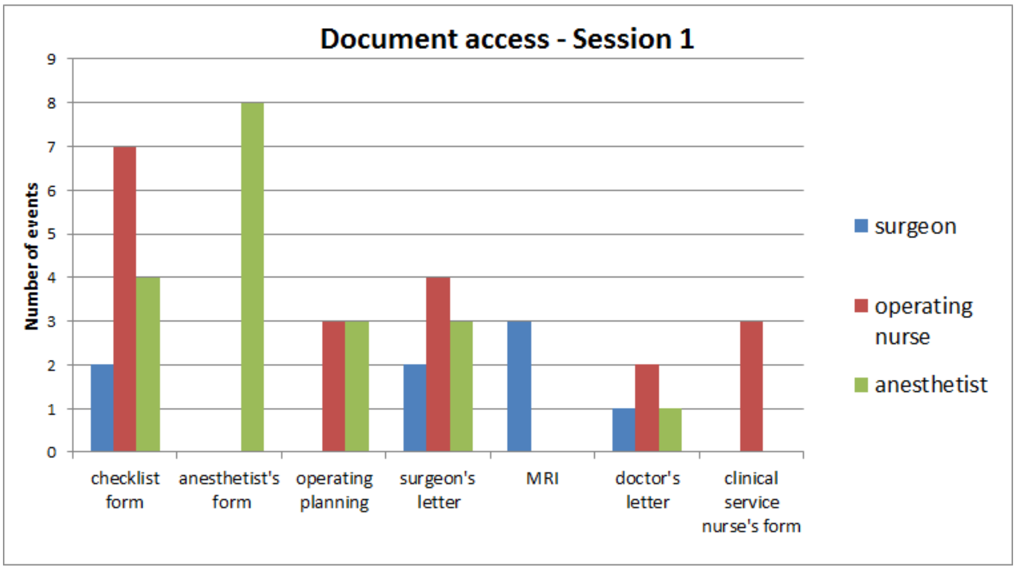


Figure 18.7 – global document access during game session 1.

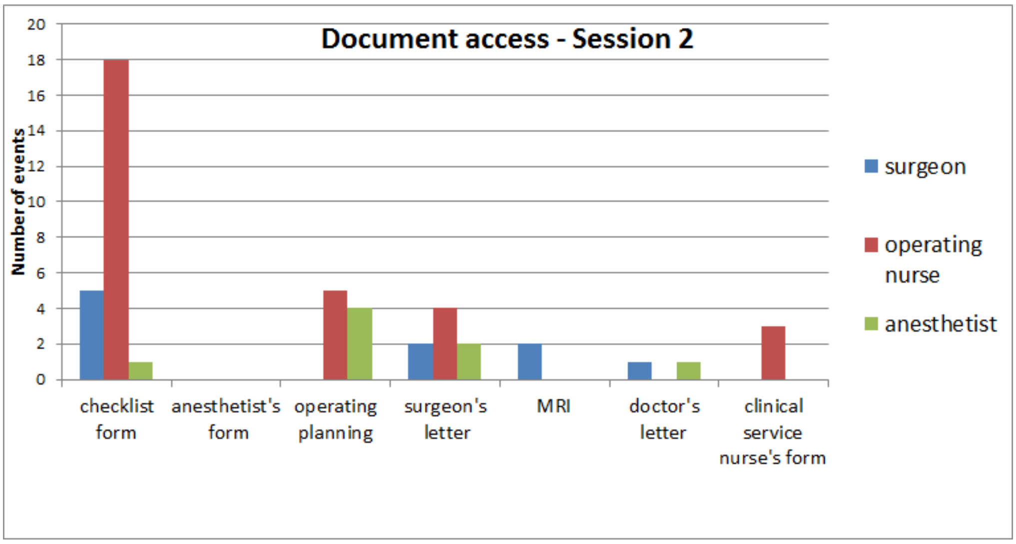


Figure 18.8 – global document access during game session 2.

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 $\leftrightarrow$ operating nurse : 2 different questions asked\\
surgeon $\leftrightarrow$ nurse : 2 same questions asked quasi successively\\
anesthetist $\leftrightarrow$ surgeon : 1 question asked\\
operating nurse $\leftrightarrow$ anesthetist : 3 same questions asked quasi successively\\
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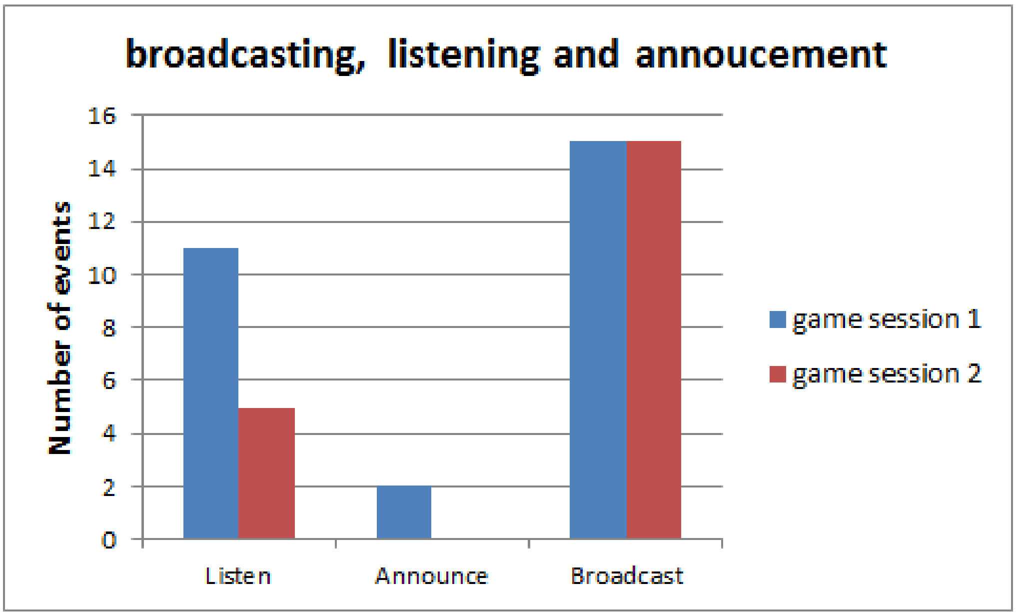

Figure 18.9 – global view : Use of broadcasting, listening and announcement.

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.

18.2.5 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.

18.3 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.

18.3.1 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" 18.1.

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 18.1 – 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, five 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.

Two 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 graphic 18.2.

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.

18.3.2 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.

18.4 Conclusion

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 here 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 surgery 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 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.

Chapter

19

Experiments to assess the decision making system

The experiments whose results are presented and discussed in this chapter were conducted between 2015 and 2016 and served the mere purpose of demonstrating the usability of the decision support system included in 3DVOR. The game scenarios chosen focus on real-life professional situations pedagogically designed to trigger debates on predefined topics at key moments during the virtual surgery: anomaly with the patient's identity or the surgery site, discrepancy in the patient's record, and decision to transfer the patient to the OR.

The first prototype was experimented first in 2015 with student nurse anesthetists to check the usability of the communication system and the virtual operating room environment that support the collaborative-decision making system. Then, it was experimented later in 2016 with teams composed of students nurses, student nurse anesthetists and medical interns. The scenarios were improved in 2016 so as to limit the number of times a decision could be postponed. Indeed, we found out during the first experiment [Pons Lelardeux+2016] that some decisions could be deadlocked by the leader stubbornly and repeatedly picking the option "Continue to check" when the rest of the team disagreed. This disagreement could only be solved by the intervention of the trainer. The improvement of the system consists in disallowing the "Continue to check" option after three unsuccessful trials so that an actual decision, either positive (eg: "Transfer the patient", "Tick the checklist item") or negative (eg:"Abort the surgery"), can finally be made.

19.1 Method

For demonstrating the system's usability, we used a quantitative approach which consisted in identifying patterns within 59 debates recorded during 21 game sessions (2 in 2015 and 19 in 2016).

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. The debate topics were distributed this way: 17 related to the patient's identity, 7 on the surgery site, 30 on the patient's transfer and 5 on the patient's record. During the 21 sessions, every player's interaction in the game was recorded in a database. This dataset allowed for a meticulous analysis of the different decisions made during the game sessions using the voting procedure.

Table 19.1 – Debate patterns

Start	End	Comment
A	A	All participants agreed with each others throughout the debate.
A	B	The participants agreed at the beginning and disagreed at the end.
B	A	The participants disagreed at the beginning and agreed at the end.
B	B	The participants disagreed throughout the debate.

The method consisted in comparing the opinions expressed by the teammates when the debate starts, ends, and when the decision is finally made by the leader. Let A represent a situation of total agreement among all participants (every teammate has the same opinion) and B a situation of disagreement, either partial (one participant has a different opinion than the 2 others) or total (every participant has a different opinion), each debate can be associated with a pattern representing the situations at the beginning and at the end of the debate (see Table 19.1). On non-trivial patterns, a finer-grained analysis can be undertaken by looking in detail into the behavior of each participant during the debate (minds changed, arguments placed or withdrawn) and the final decision of the leader. The results are presented in the next paragraphs.

19.2 Results and discussion

All teams used the decision-making system to debate and express their opinion on a particular subject. The decision-making system is user-friendly enough to be used in a learning context since one game session only did not contain any vote. The data show that on average 2.8 debates have been triggered per session on different topics. This is relatively coherent regarding the part of the WHO safety checklist concerned by the scenarios. The debate related to transferring the patient was more often triggered than the others (30 times against 29 for the three others together). This can be explained by the fact this is a scenario-blocking decision, forbidding the team to advance the narrative further. On the contrary, the other debates can be skipped without practically blocking the surgery procedure, although overlooking those is a threat for the patient's safety. Looking in detail into the arguments used in the debates related to patient's transfer, we also found out that many of them were related to anomalies detected in the patient's identity or the surgery site or the patient record documentation. This means that although these debates were less used during the game, the players still felt concerned about checking the potential risks and expressing their doubts to the rest of the team, only they did so in the wrong –or, say, unexpected– place.

Table 19.2 lists and counts the different situations that were faced by the teams of learners, and the vote outcomes. Patterns A-A and B-B are significantly the most frequent. Either all participants agreed throughout the discussion or they did not, neither at the beginning nor at the end of the discussion. The results on the pieces of information used to convince the others and the number of times participants changed their mind help us to understand what are the dynamics inside the negotiation. On average, 5.23 arguments per vote were used and

Table 19.2 – Debate patterns distribution

Pattern	2015	2016	Percentage
A-A	4	16	33,9%
A-B	1	2	5,1%
B-A	1	9	16,9%
B-B	7	19	44,1%
Total	13	46	

0.71 were removed from the discussion. On B-B patterns, on average 4.4 arguments were given to support opinions and at least one participant changed their mind during a debate. Therefore, the leader had to make a decision although some of the teammates disagreed.

We focused on B-A and B-B patterns to identify the reasons why teammates would change their mind. From the leader's point of view, typical behaviors were observed regularly throughout the dataset, which were classified in 9 categories detailed in the list below from L1 to L9. The details of each vote was analyzed and distinctive behaviors from the leader were counted and reported on Table 19.3. During a vote, several behaviors can be observed or on the contrary none, which explains why the figures on Table 19.3 are inconsistent with the number of votes or the number of sessions.

L1 Leader rallies the expert's argued opinion

L2 Leader rallies another participant's opinion who is not an expert

L3 Leader rallies the expert's opinion who did not argued

L4 Leader yields the opinion of the majority

L5 Leader maintains their opinion

L6 Leader opposes to the expert's opinions who argued with at least a relevant piece of information

L7 Leader opposes to the expert's opinions who did not argued with a relevant piece of information

L8 Leader opposes to the opinion of the majority

L9 Leader do not make a final opinion (time over or 'Continue to check')

Table 19.3 – Leader's behaviors count (2016 experiments)

Behavior	L1	L2	L3	L4	L5	L6	L7	L8	L9
B-A	5	1	0	2	1	0	0	0	4
B-B	1	1	0	0	14	2	7	3	8
Frequency (%)	21.4	7.1	0	7.1	53.6	25	10.7	3	42.9

Analyzing the 46 cases of discussion of 2016, 28 debates have begun with a disagreement (frequencies on Table 19.3 are calculated on the basis of these 28 debates). We observe that most of the time, the leader has maintained his opinion (53.6%) and/or choosen the answer "Continue to check" when it was available (42.9%). When in contradiction with an expert, the leader has rallied to his opinion when one or several relevant arguments were placed (21.4% of the time) or, decided to maintain his opinion when no arguments was used by the expert (25% of the time). If we consider first the outcome of the debates, we can notice that when the debate has ended with an agreement (pattern B-A, first row on Table 19.3), most of the time either the leader has rallied to the argued opinion of an expert, or the team as a whole has agreed to choose the dismissive answer. When the participants could not reach an agreement (pattern B-B, second row on Table 19.3), it was mainly the fault of the leader deciding not to change his opinion. On several occasions, the leader has even maintained a conflicting opinion with the expert, which can be explained by the absence of any valid argument which could have been used by the expert to influence the leader. These figures tend to confirm that arguments in a debate are decisive criteria for the outcome of a decision-making process.

19.3 Conclusion

We have presented a system for players immersed in a virtual operating room to make collaborative decisions. The system has not been designed to provide any kind of assistance in the decision making but simply to facilitate the debate and collect enough data for the decisions to be analyzed and debriefed at the end of each game session. The system should therefore be evaluated in terms of how expressive and useful the embedded features are. Preliminary qualitative results indicate a success from this point of view since the system was used many times in every experiment session (except 1) and collected data could actually be used for debriefing the players.

Looking more in detail into the behaviors exhibited in-game by the leader, who is the final decision-making player, has allowed to confirm the role of argumentation in a debate. Relevant arguments placed by experts were able to inflect the decision of the leader whereas the lack of a relevant argumentation was the main cause of a rooted disagreement.

The experiment was set in a virtual operating room but we believe our findings could be generalized to other multi-professional workplaces where conflicts can appear and be solved by debating and making collaborative decisions. Future work aims to transpose 3DVOR's decision-making activity into an industry-related context.

Chapter

20

Experiments to assess the model of objectives

The virtual collaborative environment was experimented at the University Hospital of Toulouse with the participation of last-year undergraduate students from the Anesthetist Nurse School of Toulouse and the Operating Nurse School of Toulouse. The experiment was separated in two steps. The first part of the experiment was dedicated to familiarize the students to the virtual environment. The second part of the experiment consisted in confronting them with an unpredictable situation.

Height teams composed of three students were involved in these experimental training sessions. Each student plays their role as a professional in the virtual operating room. All the students had already worked in a real operating room during a professional internship. Like any medical simulation, the experiment included a succession of three stages: i) a briefing, during which was explained how the session would be run together with an introduction to the training objectives; ii) the activity itself (or game stage) during which the participants played out the scenario specially designed to work to the teaching objectives relating to the established curriculum; and iii) the debriefing.

20.1 Experimental protocol

The experimental protocol included four steps: Firstly, the teacher made a briefing on the virtual environment and its main features and explained how to play the game. Natural conversation between learners was banned during the game. Everyone have to use the communication system provided by the virtual environment to exchange opinions and information. Secondly, the learners tried to familiarize themselves with the virtual environment, particularly how to talk to the patient, how to move to the computer which displays the MRI, how to discuss with the other teammates, etc. They used first a scenario presenting a standardized situation without any difficulties nor traps. Two students composed the first team in the standardized situation while the third one played the same scenario in parallel with a virtual non-playing character. At the end of this step, a debriefing was brought to recap the different features and their usage. Thirdly, the team of three students tried to manage a new professional situation presenting some irregularities. Fourthly, at the end of the session, an automatized and personalized debriefing was produced to support the trainer and provide feedback to students on what risks were mastered and what should have been done to reduce risks. During all training sessions, computer data, video of training sessions were recorded.

20.2 Two training situations

Two training situations have been designed for this experiment to train people on the patient security checklist which is supposed to be used to prevent wrong patient error and wrong site surgery. The educational context is based on the first phase of a surgery, that is the first column of the checklist: from the patient's arrival to the induction of anesthesia. The three first checklist's items are concerned, listed in Table 20.1.

Table 20.1 – The first 3 questions of the patient safety checklist.

Question	Admissible answers
Is the patient's identity confirmed?	Yes, No, Not applicable
Is the patient's operating site confirmed?	Yes, No, Not applicable
Has the patient/family confirmed his/her consent?	Yes, No, Not applicable

The first situation is based on a standardized professional situation and the second one is a non standardized situation that contains multiple anomalies. Both present a patient who has a cerebral tumor. Depending on the size of the tumor, the patient is supposed to be able to talk or not. Students are expected to identify the anomalies, exchange on them, take appropriate decisions before they fill the checklist's items and move the patient to the operating room. The second educational context imposes to adapt the security rules when the team is facing to non-standardized situation (ie: with an unpredictable anomaly). For example: the patient cannot state his name, information is missing on the medical record, etc.

The scenarios are both divided into three steps:

1. Verifying patient's identity
2. Verifying patient's operating site
3. Move the patient to the operating room

And the three main educational objectives are: (i) Reducing the risk of patient's identity error applying the security checklist (ii)Reducing the risk of patient's wrong site applying the security checklist (iii) Adapt the procedure to a specific and near-miss context if they identify some anomalies.

20.3 Results

The question of debriefing in the context of an operating room is a delicate one as it relates to the complexity of the system. Indeed, teamwork in the operating room cannot be summarized as the straightforward coexistence between technically competent individuals. The operating room can be considered to be a complex system since it functions in a dynamic and uncertain environment, with the professionals concerned maintaining among themselves relations that can be both hierarchical and complementary around a shared goal of dispensing optimum care for the person being operated on. Each surgical team and each of its members have specific skills and knowledge. The system of objectives presented here tries to take into account both each member's capabilities in carrying out their tasks and the ability of the team to ensure precise co-ordination.

20.3.1 Step objectives

Among the twenty training sessions, ten sessions focused on the same standardized situation and ten sessions focused on the same near-miss situation. Each training session lasted in average two hours, during which one hour was actually spent playing the game. Among all the training sessions, most teams succeeded to reach the step objective "Move the patient to the operating room" in the standardized situation whereas they failed to managed the near-miss situation (see Table 20.2).

Table 20.2 – Synthesis of reached step objectives

Objective Scenario	Standardized	Near-miss
Check the patient's identity	6	6
Check the operating site	5	5
Move the patient to the operating room	7	0

20.3.2 Educational objectives

The first objective consists in evaluating if the teams managed to reduce the wrong patient error risk applying the checklist. The second one consists in evaluating if the teams managed to reduce the wrong site risk applying the checklist. Tables 20.3 and 20.4 show the number of times the team completed the main objectives.

Table 20.3 – Educational objective: "Avoid the patient's identity error risk" - Number of times the teams succeeded

Objective Scenario	Standardized	Near-miss
Avoid the wrong patient error risk applying the checklist	0	2
Confirm the patient's identity on the checklist	5	3
Adapt the security procedure to the context	NA	4

Table 20.4 – Educational objective 'Avoid the wrong site error risk' - Number of times the teams succeeded

Objective Scenario	Standardized	Near-miss
Avoid the wrong site error risk applying the checklist	3	1
Confirm the site on the checklist	4	2
Apply the standard procedure and fulfill the checklist	4	3

Even though most of the time teams failed to reduce the wrong site risk applying the checklist, just under half of the teams checked little more than half the micro-objectives (see Table 20.5).

Table 20.5 – Success rate for the objective "Avoid the wrong site risk". Half of the teams were not able to complete any objective whereas other teams managed to complete partially (or entirely) the game objectives.

Team number	1	2	3	4	5	6	7	8	9	10
Success rate(%)	0	0	75	0	33.3	100	100	60	100	50
Team number	11	12	13	14						
Success rate(%)	100	60	0	83.3						

The most common error made by the teams playing to the near-miss situation focused on the item "Is the patient's operating site confirmed?". Most of the time, this item has not been checked. Table 20.6 lists the main errors stored by the system.

Table 20.6 – frequency of failures for the educational objective "Avoid the wrong site risk".

Type of failure	Count
The item "Is the patient's operating site confirmed ?" was not checked	8
The operating nurse had not checked the operating site on the MRI	4
The surgeon has not confirmed the operating site to the checklist manager	3
Nobody sent to the checklist manager the surgery and the operating site told from the patient	2

Among the teams that were able to fulfill a part of the objective "avoid the wrong site surgery risk", 4 teams succeeded with the following activities: (i)the surgeon player had examined the patient's motor function and the patient's communication ability to identify the operating site, and (ii) the surgeon player had checked the surgery site on the MRI. Yet, only one surgeon player has sent the crucial information to the checklist manager.

20.4 Conclusion

The collaborative virtual environment featured in 3DVOR simulates teamwork in the operating room in different real-life professional contexts. This environment was designed to be used in a learning context. We have presented a model designed to specify, record and store different kinds of objectives: "step" objectives, shown to the students for them to get their bearings in the scenario, and; "failure objective" or "success-objectives", hidden to the students yet allowing for identifying what was missed in the scenario. Objectives are combined in a tree-like structure with a specific grammar that helps to build, out of simple contextual actions, conversations or decisions, meaningful team objectives that enable to recap their behavior and the expected outcomes. This model was used to specify educational objectives connected to the WHO surgical checklist. The behavior of students has been recorded individually and collectively during twenty training sessions and the model has successfully been proven able to reveal their successes and failures, and therefore to evaluate their teamwork efficiency in critical situations. Future work aims to design dynamic information as blood pressure that change dynamically during the surgery to build more complex scenario and its educational objectives that take in account the temporality of events.

Part V

Conclusion and further works

Chapter

21

Synthesis in French

Démarche et contributions

De nombreux accidents, dans les transports, l'industrie ou encore dans les parcours de soins résultent d'un enchainement d'événements ponctuées d'erreurs humaines et en particulier de défauts d'organisation, de défauts de communication ou de décisions inappropriées. Dans ces contextes socio-techniques dynamiques, la formation collective des équipes à la gestion des risques liés à des compétences non techniques telles que le travail en équipe, la communication, le leadership et le prise de décision collaborative est un enjeu majeur. Quelques formations à la gestion des risques sont dispensées mais elles s'appuient dans la plupart des cas sur la présentation de retours d'expérience de professionnels aguerris ou bien sur la présentation de méthodes d'analyse systèmique. Peu d'entre elles proposent des mises en situation réelle dans un contexte professionnel simulé. Même si quelques initiatives existent, il reste très complexe pour un formateur de contrôler le déroulement d'une séance, de reconstruire et d'analyser l'activité collective et ensuite de proposer un débriefing adaptée sur la manière dont l'équipe a geré la situation pédagogique proposée. En effet, le caractère imprévisible du déroulement de l'activité collective est fortement lié au degré de liberté inhérent au contexte pédagogique proposé ce qui rend d'autant plus complexe la tâche du formateur. Par ailleurs, de nombreux travaux consacrés aux environnements virtuels, réalité virtuelle et serious games proposent des artefacts pour entrainer un individu la plupart du temps seul et parfois en équipe à agir, communiquer, ou prendre des décisions dans un contexte socio-professionnel conçu pour être utilisé en formation. Malheureusement, les communications entre les membres d'une équipe ou encore les prises de décision collectives s'opèrent la plupart du temps oralement et ne peuvent alors être analysées que manuellement et a posteriori.

Les principaux objectifs de cette thèse portaient sur l'entrainement des équipes à la gestion des risques liés à des defauts de comunication dans un environnement socio-technique complexe. Le travail s'est centré sur la mise en place d'un environnement virtuel, interactif, multijoueurs, temps réel permettant aux équipes de s'exercer à gérer des situations professionnelles standards ou à risque liés à des défauts de communication et/ou de prise de décision. La motivation principale a donc été de proposer dans un environnement virtuel multi-joueurs, des systèmes d'actions, de communication et de prise de décisions collaboratives permettant de contrôler la situation pédagogique dans son ensemble de manière à pouvoir automatiser la production d'un débriefing individuel et collectif à l'issu d'une séance de formation.

Pour cela, nous nous sommes attachés à proposer un ensemble cohérent de modèles et de méthodes : un environnement graphique multi-joueur temps-réel, un système de communication, un système de prise de décision collaboratif, une méthode pour concevoir et modéliser des scénarios éducatifs de formation à la gestion des risques, un modèle pour décrire des objectifs individuel ou collectifs, une méthode pour présenter un débriefing personnalisé et automatisé immédiatement à l'issu d'une partie.

Le contexte du bloc opératoire nous a servi de cas d'application et le contenu éducatif utilisé s'appuie sur des événements indésirables réels qui ont pour principales caractéristiques communes d'avoir pour origine des défauts de communication ou de prise de décision comme facteurs contributifs. Ces dimensions ont permis de déterminer les différentes étapes de la démarche.

Dans un premier temps, nous nous sommes inspirés de méthodes d'analyse d'accident survenus dans des contextes socio-techniques complexes et dynamiques pour concevoir des scénarios dédiés à la gestion des risques dans une situation professionnelle. Au travers des interactions proposées dans l'environnement, nous avons donné la possibilité aux joueurs de construire des barrières de défense contre la survenue d'incident. Parallélement, nous avons positionnés dans les scénarios des anomalies et/ou la possibilité de choisir des stratégies inadaptées ou/et de commettre des erreurs. Deux types de scenarios ont été conçus : le premier concerne des scénarios basés sur une situation initiale parfaite et l'autre concerne des scenarios basés sur une situation initiale dégradée dans laquelle des anomalies sont préalablement positionnées. Tous octroient une certaine liberté d'action à l'équipe tout en limitant le nombre de tâches réalisables par le biais d'actions et de sujets de discussions possibles.

Dans un second temps, nous avons modélisé l'activité potentielle d'une équipe (actions individuelles, actions collectives, informations disponibles, débats probables. . .) et proposé des interactions permettant de simuler la collecte d'informations, la communication (au sens manipulation et échange d'informations), le débat et la prise de décision. Le système de communication ne s'appuie pas sur un système de "chat" écrit ou oral mais consiste à manipuler des informations brutes par le biais de bulles graphiques disponible dans la mémoire virtuelle de son personnage. Les interactions proposent des métaphores graphiques illustrant la collecte d'informations, leur mémorisation, leur écoute, leur diffusion et la demande d'informations. Les utilisateurs peuvent se poser des questions et y répondre par le biais de bulles graphiques disponibles dans leur mémoire virtuelle. Le système de prise de décision s'appuie également sur la mémoire virtuelle du personnage et propose une pré-selection d'informations en relation avec le sujet du débat à condition que celles-ci aient été préalablement collectées et mémorisées.

Dans un troisième temps, en se basant sur ces modèles, nous avons proposé un modèle de définition d'objectifs pédagogiques de manière à contrôler les écarts entre l'activité attendue et celle effectivement réalisée durant la partie. Ce modèle nous a permis de décrire précisement les objectifs à atteindre seul ou collectivement. Ces objectifs de succès ou d'échecs peuvent se composer à la fois d'actions, d'échanges d'informations et de décisions. Ce modèle nous permet également de combiner des objectifs entre eux et ainsi d'en créer de complexes. Ainsi, l'activité individuelle et collective peut être entièrement contrôlée, analysée et comparée en temps réel aux objectifs attendus ce qui permet d'automatiser la présentation d'un débriefing en fin de partie. De plus, la structure arborescente des objectifs complexes permet de graduer le niveau de maitrise des risques associés à une session de jeu.

Enfin, dans un quatrième temps, nous avons proposé une organisation spécifique du débriefing liée au contexte particulier de la formation à la gestion des risques. Cette organisation consiste à inverser certaines étapes préconisées dans les méthodes d'analyse d'incidents et à les adapter au contexte de la formation. Ainsi, à l'issu d'une session de jeu, une auto-évaluation est proposée aux joueurs pour qu'ils puissent individuellement identifier les causes profondes qui selon eux ont pu conduire à l'incident qu'ils ont pu provoqué. Ensuite, par exemple dans le cas où ils n'ont pas provoqué d'incident, une auto-évaluation de leurs performances associée à chacun des risque qu'ils ont eu à gérér leur est proposée. Enfin, une analyse factuelle comparée et automatiquement calculée leur est présentée de manière à ce qu'ils puissent collectivement identifier les manques, les erreurs et les succès de l'équipe et des individus.

Bilan et points forts

L'environnement graphique a été conçu pour reproduire de manière réaliste l'environnement socio-technique complexe professionel. Sur ce point, soixante dix huit pour cent (78%) des utilisateurs déclarent que l'environnement virtuel créé rend bien compte de la réalité d'un bloc opératoire. Il apparait aussi que cet environnement et en particulier l'univers graphique a été particulièrement apprécié des utilisateurs. Quatre vingt un pour cent (81%) déclarent l'apprécier. Ces résultats confirment que la méthode utilisée pour représenter l'environnement, l'ancrage des activités professionnelles dans l'environnement graphique mais aussi les déplacements, les personnages a été particulièrement efficace.

Les expérimentations montrent que les systèmes d'interactions mis en oeuvre sont très intuitifs. Ils ont été rapidement pris en main par les utilisateurs même s'ils ont pu parfois générer une certaine frustration. En effet, le système de communication n'étant pas basé sur du "chat" ni écrit ni oral, il limite par essence la liberté d'expression et présente un caractère restrictif qui peut génerer de la frustration et de l'animosité amplifiée parfois par les caractères d'urgence ou de criticité de la situation vécue virtuellement. Pour autant, la collecte et l'échange d'informations fonctionnent bien et ont été rapidement pris en main par les utilisateurs. Ces résultats sont corroborés par l'analyse des questionnaires distribués en fin de séances d'expérimentation. En effet, soixante douze pour cent (72%) estiment que l'environnement est facile à utiliser. Cinquante trois pour cent (53%) des utilisateurs ont le sentiment d'avoir appris rapidement à utiliser l'environnement virtuel proposé. Pour autant, quarante quatre pour cent (44%) pensent avoir commis des erreurs de manipulation.

Le système de prise de décision est lui aussi suffisament intuitif pour être pris en main quasi-immédiatement même si dans certains cas très particuliers il peut être perçu comme un outil de classement d'arguments destiné à un usage individuel. Ce cas particulier porte sur l'usage pour la toute première fois du système et dans le cas particulier où aucun autre participant n'a encore argumenté d'opinion. Dans ce cas, un faible nombre d'utilisateurs a agi comme si ce système était un système de reflexion individuel amont à une prise de position collective. Cela se caractèrise par une tentative de classement des arguments detenus dans des colonnes associées à des opinions distinctes. L'utilisateur semble considérer qu'il est le seul à pouvoir visualiser l'interface qui pourtant est partagé par tous et essaie de classifier les informations qu'il détient afin de se forger sa propre opinion. Pour autant, dès que l'utilisateur tente de classer un argument dans une seconde colonne symbolisant une autre opinion, les arguments précédement positionnés pour supporter la première opinion disparaissent. L'utilisateur voit apparaitre au fur et à mesure les opinions et arguments des autres participants sur son interface et comprend le caratère synchrone et collaboratif de la démarche. Même si ce cas particulier reste marginal, il est important de noter que même au sein d'un envionnement collaboratif réalisé pour de la formation en équipe, l'individu est tenté de rester ego-centré et non de se projeter dans une reflexion collective. Ce point de vue est conforté par les comportements individualistes d'utilisateurs qui cherchent à gérer seul la situation proposée. Ces comportements individualistes ont aussi été remarqués par des joueurs qui tentaient de collecter des informations seuls sans faire appel aux autres membres de l'équipe. La stratégie de conception de scénario qui consistait à dispatcher des informations et des tâches à certains rôles uniquement a donc permis de forcer les joueurs à collaborer.

Un de nos objectifs était de recréer dans un contexte de formation les conditions d'apparition d'un incident mettant en jeu plusieurs acteurs ce qui est extrêmement difficile et même impossible dans le cas de formations pluridisciplinairse qui auraient lieu dans un environnement physique. Cet objectif a donc était parfaitement atteint. En effet, dans de nombreux cas, les équipes ont produit virtuellement une chaine d'événements qui a conduit à un événement indésirable virtuel.

Les expérimentations ont également montré que le contrôle de l'activité au sein de l'environnement a permis de réveler des comportements, des stratégies et des niveaux de maitrise différents selon les équipes et les situations proposées. L'utilisation de cet environnement virtuel collaboratif a permis de révéler des désaccords qui ont parfois générer des conflits. Dans certains cas, des émotions de frustration, d'agacement ou de désarroi ont gagné certains participants soit parce que les joueurs avaient le sentiment de ne pas pouvoir infléchir le cours des choses, soit parce qu'ils avaient le sentiment de ne pas pouvoir exprimer véritablement leur point de vue, soit parce qu'ils étaient en total désaccord avec un autre participant ayant un pouvoir décisionnaire. Il a été remarqué que dans de nombreux débats les équipes n'étaient pas d'accord sur la conduite à tenir pour gérer la situation. Une analyse détaillée des débats nous a permis de souligner que comme en réalité, le décideur avait tendance à suivre l'opinion d'un expert du sujet abordé quand ce dernier fournissait un argument irrefutable. Ceci permet donc d'attester du caractère immersif et réaliste de l'environnement proposé mais aussi l'efficacicté des systèmes et modèles proposés.

La génération de désaccords au sein de l'équipe dans l'environnement virtuel a permis au formateur de mener des discussions nourries et constructives quant aux bonnes pratiques à suivre en pareil cas. Au cours du débriefing oaral, chacun a pu apporter son point de vue sur la façon de réagir et de gérer la situation qu'il pensait avoir vécue. Dans la majorité des cas, les équipes avaient une représentation réaliste de la situation vécue mais n'avaient pas pour autant la bonne analyse quant à la conduite à tenir dans un pareil cas. Les temps post-jeu ont pu alors être des moments d'échanges et de confrontation des pratiques entre professionnels et semi-professionnels. Dans d'autres cas, les risques ont été majoritairement maitrisés et des incidents évités soit par l'utilisation de procédures de sécurité, soit par la mise en commun d'informations qui ont conduit à une prise de décision adaptée à la situation courante. Les expérimentations ont montré que dans la plupart des débats pour lesquels il y avait un désaccord, le décideur avait tendance à suivre l'opinion d'un membre de l'équipe identifié comme un expert à condition que ce dernier ait argumenté son propos.

La méthodologie utilisée pour créer des scénarios de formation à la gestion des risques en équipe a donc été particulièrement pertinente et efficace.

L'usage montre que l'environnement collaboratif de formation à la gestion des risques permet de mettre les équipes dans des situations professionnelles virtuelles tout en les affranchissant du cadre organisationnel, hiérarchique et structurel complexe de leurs établissements ou services cliniques. Il a permis de génerer des échanges inter-professionnels hors du contexte clinique réel qui peut parfois être vécu comme très oppressant. La mise en situation du logiciel dans un contexte de formation a rendu possible des situations d'échanges de pratiques au sein des participants dans un esprit constructif et déculpabilisant.

Les mises en situation dans un contexte de formation réel ont montré que l'environnement virtuel collaboratif fonctionne parfaitement mais ne peut pas être utilisé par les étudiants sans la présence d'un formateur. La présence d'un formateur est indispensable à la fois pour mettre en oeuvre et orchestrer la séance de formation mais aussi pour débriefer les équipes à l'issu des sessions de jeu.

Du point de vue du formateur, l'outil est perçu comme un support innovant permettant de mettre en scène les étudiants dans des situations professionnelles dans un contexte sûr et sécurisé. Les formateurs ont apprécié ces mises en situation car elles ont permis de mettre en évidence concrètement les comportements et les raisonnements des étudiants agissant en contexte interprofessionnel ce qui n'était pas possible jusque-là. Les formateurs notent que les étudiants peuvent prendre le temps de réfléchir avant d'agir au sein de l'environnement virtuel sans se laisser emporter par la dynamique de la situation ce qui est moins le cas en situation réelle ou dans le cadre de formations par la simulation haute-fidélité. L'usage d'un ordinateur favorise le recul nécessaire face à une situation critique ou problématique. Les situations proposées étaient suffisamment réalistes pour induire une forte immersion et implication des étudiants même si le caractère numérique du dispositif a parfois eu un impact négatif en première approche pour un petit nombre d'étudiants réfractaires aux outils numériques. Les étudiants se sont montrés dans une très grande majorité très enthousiastes et ont été immergés dans le scénario au point de se révéler vexés de ne pas pouvoir suffisamment insister auprès du leader et influer sur sa décision lorsque celui-ci n'était pas de leur avis. Selon le formateur, l'utilisation de ce type de support est aussi l'occasion de faire découvrir concrètement le travail et les pratiques des autres corps de métiers et ainsi de favoriser les échanges interprofessionnels. Ces occasions sont d'ailleurs extrêmement rares. Les fonctionnalités dédiées au formateur ont été globalement appréciées et lui ont permis de suivre en temps réel l'activité de l'équipe dans l'environnement virtuel. Les formateurs ont ainsi pu comprendre tout au long de la session le point de vue de chacun des étudiants sans interrompre la session. Les situations réalistes proposées ont donné lieu à des dilemmes ce qui est un formidable exercice pédagogique. Ce type de formation apparait au formateur comme un complément indispensable aux formations par la simulation haute-fidélité pratiquée dans des pièces réelles reproduisant le contexte professionnel.

Enfin, il a été identifié l'importance pour le formateur de pouvoir s'appuyer sur un debriefing automatisé pour mener les échanges et la discussion immédiatement après la session de jeu. En effet, le formateur ne peut pas monitorer seul l'activité de tous les membres de l'équipe à chaque instant. Il est aussi impossible pour lui de connaitre les motivations et le raisonnement de chaque participant qui a conduit à mener telle ou telle action, ou à soutenir telle ou telle opinion. L'utilisation des modèles d'objectifs nous a permis de produire de manière automatique un débriefing personnalisé synthétisant les manques, les choix et stratégies déployées par les équipes pour gérer la situation pédagogique proposée. Ces débriefings présentés sous forme graphique mais aussi sous forme de fichier postscript a servi de support aux formateurs pour diriger le temps oral de débriefing immédiatement après la session de jeu. L'environnement développé a permis de monitorer l'activité et de la présenter globalement au travers d'indicateurs qui permettent de suivre l'activité et le raisonnement de chacun des participants. Ceci représente une plus-value certaine sur laquelle les formateurs ont pu s'appuyer immédiatement pour conduire une formation.

Enfin, même si un plus grand nombre d'expérimentations devra être mené pour consolider les résultats avancés, soixante douze pour cent (72%) des étudiants-testeurs estiment avoir un sentiment d'apprentissage des procédures de sécurité en utilisant cet environnement. Ce résultat est en adéquation avec le principal but recherché.

Perspectives

Une étude appronfondie de l'usage de l'outil en situation de formation devra être menée pour consolider les premiers résultats obtenus en terme d'acceptabilité, et d'utilisabilité. Une étude pourra aussi être ménée de manière à analyser la dynamique d'apprentissage et les compétences transmises au travers de séances de formation intégrant cet outil. Le croisement des résultats basés sur l'activité réelle de l'équipe et les sentiments exprimés du niveau de maitrise de risques de chacun des participant pourraient être effectué de manière à évaluer la conscience de la situation vécue par chacun des participants. La réussite de missions au sein de l'environnement virtuel proposé pourrait amener la certification de compétences non techniques des utilisateurs ayant suivi une formation avec cet outil. Du point de vue technique, quelques améliorations pourraient également être envisagées. L'environnement propose aujourd'hui un système de gestion des informations dynamiques (telles que le rythme cardiaque ou encore la saturation pulsée en oxygène) qui devrait venir enrichir le modèle de description des informations afin que ces informations dynamiques puissent être collectées, mises à jour et utilisées par les joueurs en cours de simulation. Ces propositions permettraient de gérer des informations évolutives à la fois au travers de la mémoire virtuelle et des systèmes de communication et de prise de décision. Ces modèles dores et déjà mis en oeuvre, devront être testés, expérimentés et validés dans des expérimentations futures. Par ailleurs, l'analyse des expérimentations a mis en évidence une piste d'amélioration concernant la prise de décision et la synthèse fournie au formateur à l'issue d'une partie. Il est envisagé de fournir lors de la première utilisation du système de décision des éléments graphiques et textuels d'accompagnement qui permettrait de lever l'ambiguité entre système préalable à la décision individuelle consistant à classer des arguments et système de prise de décision collectif consistant à donner aux autres son opinion en l'argumentant.

Un troisième axe d'amélioration est envisagé. Il consisterait à fournir au formateur des indicateurs plus fins tels que la liste des débats effectués par l'équipe, les sujets abordés et les décisions prises en fonction de l'état de connaissances de chacun. Ces résultats pourraient par exemple être présentés sous forme de chronogramme indiquant la valeur de certains paramètres afin de donner un aperçu global de l'enchainement des événements qui a conduit à la fin de partie. Une présentation graphique plus synthétique sous forme de radars de compétences est également envisagé.

Enfin, afin de s'assurer de la généricité des modèles proposés, il est envisagé de poursuivre ces travaux en les transposant dans un autre contexte que celui du bloc opératoire. En effet, d'autres systèmes socio-techniques complexes similaires tels que celui de l'aéronautique, de la gestion d'offres technico-commerciales ou bien le management d'industries 3.0 sont parfaitement en adéquation avec les besoins exprimés dans cette étude.

Chapter

22

Synthesis in English

Challenge and Contributions to achieve the objectives

Many accidents in industry, transportation or care pathways result from successive unpredictable events that include organization defaults, communication defaults or non suitable decisions. In such socio-technical and dynamic systems, team training for risk management is crucial especially to train non technical skills such as teamwork, communication, decision-making and leadership.

Although many experts stressed the training needs in terms of simulation to improve risk management, few programs propose team training on risk management. Most of risk management training focus on technical skills, storytelling of real adverse events or learning techniques of analysis that make easy to understand what happened and what should have been done. Disseminating knowledge and sharing experience is essential to improve risk management learning. The fact is that reproducing a socio-technical learning context is complex. As a result very few courses propose to simulate a real professional context. The first point for the trainer is to control the running of the simulation, to build and limit the complexity of the professional context in an educational purpose. The second difficulty for the trainer is to follow in real-time the students' team activity, to analyze the way they manage the professional-like situation and to product a roll-up of their performance. The unpredictable nature of a teamwork activity in a complex and dynamic context is hardly linked to the level of freedom granted to the participants in the educational context. The more the level of freedom granted to the students is, the harder the task for the trainer is.

Many researches on virtual environment, virtual reality and serious games propose issues to train an individual who is typically alone but sometimes integrated in a team. The aim consists in acting, communicating, or make decision in a socio-professional context that has been designed to be used in a learning context. Unfortunately, in a very large number of cases, dialogue between team members and decision-making are treated orally (natural speaking is used). As the result, they can not be analyzed in real-time. A manual analyze is realized a posteriori.

The main objective of this thesis was to train team to manage risks linked to communication defaults or decision-making defaults in a socio-technical and dynamic environment. The work was centered on the implementation of a real-time and collaborative virtual environment that should enable teams to train to manage real-life-like professional situations where they could be faced both to perfect standardized situations and irregular and unpredictable situations. To that end, we proposed a consistent set of systems and methods: a graphical multiplayer environment, an action system, a communication system, a collaborative decision-making system, a method to model and design educational scenario for risk management, a model to describe educational objectives both for individual and collaborative tasks, a method to present and debrief a training session. This consistent set enables us to provide a multi-player real-time environment where the educational context is entirely controlled and the teamwork can be monitored. As a result, a debriefing report is automatically produced immediately at the end of a training session.

The context of the operating room has been identified as a concrete area of application. The educational content used is based on real adverse events. These adverse events have common characteristics: a communication or decision making defaults have been identified as a contributing factor. Targeting the main purpose, the approach has been separated into different steps.

Firstly, we present a method to design multi-player educational scenario for risk management in socio-technical and dynamic context. This method has been inspired by the systemic methods used to analyze real accidents. A dozen of scenarios in the healthcare field have been designed using this method. The method intends to cover one of the critical point: creating educational and entirely controlled training environments that support providers to train staff to improve their teamwork performance making them understand the importance applying or adjusting safety recommendations. Designing scenarios based on real-life situation for risk management training consists both in (1) representing a perfect initial situation with competitive experts who made zero error before the team must manage the current situation and (2) representing an irregular situation where experts made mistakes that can lead to an incident if the errors are not tracked and fixed in time. If they are not fixed in time, problems will reveal as being part of the causal chain of events that leads to an adverse event. To that end, two categories of multi-player scenario have been designed. The first one represents a regular situation embedded in a standardized scenario. It aims to train teams to apply safety recommendations and security process. The second one represents an "irregular situation" embedded in a critical scenario. It aims to make team understand the interest of applying or adjusting policy safety procedure to avoid accidents. Designing such a scenario is more complex because it requires also analyzing the chronology of events before an accident and identifying the causal chain of events and their root-causes. The method described here has been inspired by the systemic method used to analyze real accidents that occurred in socio-technical and dynamic systems. Basing our thoughts on systemic methods analysis, we designed "irregular situations" both dispatching failures or errors in an initial perfect situation and providing erroneous available issues during a decision-making or inappropriate tasks in the cloud of possible tasks. Both in ”regular“ and ”irregular“ situations, a relative freedom is granted to the players with the specific intention to limit the number of achievable tasks through interactions and possible topics of discussion. Through interactions provided in the virtual environment, we make players able to build defense barriers against the occurrence of adverse events.

Secondly, models have been proposed to structure and represent the teamwork activity in the virtual environment: individual tasks, collective tasks, available pieces of information, topic of possible debates. . . . Simultaneously, interactions have been suggested to simulate the information research, data collection, communication (by means information exchanges), debates and decision-making. The communication system is neither based on voice-chat nor branching dialogues but features graphical tags representing pieces of information and that can be manipulated as tangible objects in the virtual operating room. Graphical interactions allow users to act, collect, memorize, listen and broadcast pieces of information. The Users can also ask questions and give answers thanks to information tags stored in a graphical panel representing their virtual memory. A voting system is available to debate and vote on predefined topics. Each participant can argue with pieces of information that have already been collected in the universe.

Thirdly, we suggest a model to describe different kinds of objectives. This model helps to define (1) the script objectives that help to structure the storytelling of a scenario and (2) the educational objectives that are used to control the difference between what is expected and what has been really done. The model allows us to define the ”success objectives” (what is expected to succeed) and the ”error objectives” (what are the most current mistakes). The model allows to combine objectives and create complex objectives. The complex objectives are described with a tree-like structure that combines objectives with a specific grammar of operators. As a consequence, both individual and collective activity can be monitored, analyzed and compared in real-time with the predefined objectives. Moreover, this process particularly suits for automate the edition of the debriefing report at the end of a game session. The tree-like structure used to define complex objective enables us to graduate the score achieved by a team. We are also able to associate a score with a particular risk to manage in a scenario.

Fourthly, an innovative method has been suggested to organize the specific debriefing at the end of a risk management training. This method relies both on the professional practices recommended by the French National Authority for Health and on systemic analysis methods that are used after an occurrence of an adverse event. This method has been adjusted to provide a customized and reproducible debriefing which quality is constant and independent of the trainer’s level of expertise. In the context of risk management training, the method we propose consists in three steps. The first step consists in asking players to self-assess identifying the root cause of the virtual incident they could have provoked or determine their grade of risks management if they did not provoke a virtual adverse event. Secondly, their individual opinions are compared with their activity results and displayed on a team shared screen. Thirdly, they receive the contents of the activity report that mentions what was good, what would be done to succeed and what is missing. This report is automatically calculated from the current team activity.

Report and good points

The graphical environment has been designed to represent in a realistic way the socio-technical and complex environment. Focusing on this point, seventy height per cent (78%) of students declare that the virtual environment depicts with fidelity the operating room. It appears that the environment and especially the graphical universe has been particularly appreciate by the players. Eighty one per cent (81%) of the students declare that they appreciate the graphical virtual world. These results confirm that the method used to represent the environment, to anchor the professional activities in the graphical universe and also the animation of the virtual characters has been particularly good.

The experimental results show that the implemented interaction systems are very user-friendly. They have been quickly addressed by the players even if it is freedom-restricted because the communication system is not based neither on text-chat nor on oral-chat. Its limited-freedom nature has generated sense of frustration, animosity that have been amplified by the critical nature of the living virtual situation. Players have easily manipulated the environment to collect and exchange pieces of information.These results are strengthened by the surveys fulfilled at the end of a training session. Another result deserves further attention. Seventy two per cent (72%) of students declare that the environment is easy to use however forty four per cent (44%) of students think they have committed many manipulation mistakes in the virtual world. Fifty three per cent (53%) feel that they learn very soon to use the virtual world. This result even if it is lower than we have seen analyzing the data logged (see section 18.2) confirms that the GUI is friendly enough to allow them to act as they were in their professional activity. They mainly express that they feel free (even if the communication is restricted to bubble of information exchanges) to manage a real-life like situation.

The decision making system has also been appreciated. It was almost immediately used as it has been designed to be used. Concerning the decision-making system, it was noticed that in rare and particular cases, very few users are acting at the first time as the system was designed to allow them to build their own opinion regarding the pieces of information they know. In that case, their behavior consist in trying to classify the pieces of information they hold in different columns where a column is associated with an opinion. The user seems to consider the system as an individual and non-collaborative interface which is nevertheless shared by all. However, they quickly ascertain what for the system was designed when the arguments dropped into a column disappear as they try to classify others into an other ”opinion” column. Quickly, a participant sees the others opinion and arguments on their GUI and understands the synchronous and collaborative nature of the system. It is important to highlight this particular case even if it remains marginal. In fact, this individualistic behavior has been also identified when players try to obtain pieces of information that are not available to the role they embody. As a result, we can consider that even if the team training is focused on, each participant remains centered on themselves and tries to individually manage the current situation. This findings clearly suggest that dispatching pieces information and common tasks was a good point to force team members to collaborate and communicate.

One of the main objective was to artificially create conditions to the occurrence of an adverse event. That is extremely difficult to reproduce in a real and tangible context. Experiments prove that in most cases, teams have virtually produce a chain of events which has leaded to a virtual adverse event. As a result, the goal has been achieved.

The monitoring of the team’s activity has also revealed that the students have implemented different strategies and different behaviors. Experiments also revealed that in most cases, the participants did not have the same practices and the same implementation of safety recommendations. Their practices depend on the clinical services, the operating room management and the teams they work with. They have different qualification levels relating to risk management and safety processes according to the clinical service they work in and the professional-like educational situation they have already been faced.

Game sessions have revealed disagreements and conflicts. In some cases, students might have felt frustration, disappointment, irritation or dismay because they either felt powerless when they could not stop or inflect the dynamic or they felt disarmed while they could not express their opinion in details. or they totally disagreed with their team members or the decision-maker. It was also noticed that in most debates, the teams did not agree on the conduct to be taken to manage the situation. This means that the methodology used to design and model the risk management training scenarios was effective. A detailed analysis of the debates that are prior to a collaborative decision showed us that as in reality, the decision-maker tended to follow an expert’s opinion provided that the expert argued the latter. On these basis, we can affirm that the virtual collaborative environment we worked on is immersive.

The disagreements that were revealed during the game sessions have facilitated the trainer’s debriefing sessions because the trainer based their discourse on these disagreements to make students discuss and launch constructive debates ended by good practices. Each participant verbally explain their point of view on the situation they think they had virtually lived. In most cases, teams had a right and good representation of the situation they were faced whereas they did not have a good behavior relative to what was expected to do. In other cases, risks have been correctly managed and adverse events have been avoided because they applied safety procedures or they succeed to exchange in time relevant piece of information to help the decision-maker to make a suitable decision. As a result, it can be deduced that the methods and models used to design a multi-player virtual environment for risk management training has particularly been efficient.

The training sessions given by a trainer using this collaborative environment have stressed that it is possible to place students face to complex but controlled situations without neither any real consequences nor hierarchical structural and organizational constraints. These training sessions have allowed free, constructive and blamable-free exchanges on professional practices or otherwise beside day-to-day work. The experiments highlights that placing students' team face to an unpredictable educational situations works fine using this virtual collaborative environment although it can not be used without any trainer. The trainer is absolutely needed to manage the course and verbally discuss with the students at the end of a game session. Further research is needed however we felt that the trainers leaded their debriefing discourse basing on the main points of the automatized debriefing provided by the environment. As they can not monitor by themselves the current an parallel activity of each team member, they are not able to understand the reasoning that leads a participant to realize a task or to choose an issue.

From the trainer's point of view, the virtual environment has been perceived as an innovative tool that helps to place teams in both realistic, safe and secure pedagogical situations. These experiments had revealed some unexpected behaviors and reasoning when students faced to unusual or/and critical professional situations. This was not possible with existing training tools until such time.

Trainers note that students carefully think much more before acting than they used to when they participate to a training simulation in a real room. It appears that the computers have a positive impact and help students keep a certain distance between the situation they live and the emergency to act.

The pedagogical situations were enough realistic to quickly immerse the students. As a consequence, they were enthusiastic and sometimes they were very upset when a leader did not agree with them. The digital dimension of the training has been perceived as a negative point from a minority of students who are not familiar to digital tools.

According to the trainers, the use of such a training tool allows the students to have a concrete experience of inter-professional teamwork and exchange on inter-professional practices. This last point is highly unusual and training with this kind of environment is a good opportunity to do that.

The features dedicated to the trainers were efficient enough to allow them to follow in real-time the team activity inside the virtual environment. As a consequence, the trainers were able to understand the point of view of the team's members all along the training session without interrupting their activity.

The educational situations the students were faced have made occur some dilemma. That is a really good point for education. According to the trainers, the virtual environment they used is an essential complement of traditional training tools.

The use of decision-making system associated with the team tracing model Eurikat allowed to display immediately at the end of a game session the choices, the misses and the implemented strategies. The debriefing report is graphically displayed and available as a postscript file that can be consulted a posteriori. This report was the support of the trainer's debriefing and was immediately used to manage the debriefing period. These results confirm that the team tracing model associated with the innovative way to present a risk management training debriefing has been efficient. It represents a significant added value concerning risk management training.

Although results have to be confirmed with a larger number of experiments, seventy two (72%) per cent of students declare that they feel perform learning safety process using such an environment. This particular result matches with the main goal of this typical multiplayer digital environment.

Future works and outlooks

Further research concerning the usefulness of the environment in a training context should be investigate to confirm the first results by means acceptability and utilisability. A further study could be conducted to analyze the learning dynamics and skills development through courses that implement the virtual environment. The cross-checking of results based on the controlled activity and the feelings expressed during the debriefing should be analyzed in details to assess the level of team situation awareness. The success of a mission in this virtual environment could conduct to certificate interpersonal skills or non-technical skills. Taking a technical point of view, some improvements could be engaged especially on dynamic pieces of information (as heartbeat, forecast. . .) that could upgrade the models used to described and manipulate pieces of information. The models have already been upgraded although they never have been tested and validated. Moreover, the analysis of the experiments highlights the need of an improvement concerning the decision-making and its representation in the debriefing report. It could be interesting to present an overview of all the debates, their topic, the presence of a relevant argument and the decision-made. This overview could be represented as a timetable to help to understand the chronology of the chain of events that lead to the end of a game session. Another graphical representation should help to synthesize skills such as radars. Another improvement would consist in adding graphical assistance or individual phase of decision-making to make player understand the collaborative decision-making system. Further work would be needed to assure the generic nature of the systems and models that have been presented in this thesis. Using the models and systems to describe and train teams on others socio-technical and complex systems have to be considered and should be a great opportunity to develop team training in risk management.

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Bibliography

Bibliography by author

[1999] *A Protocol for the Investigation and Analysis Of Clinical Incidents - Clinical Risk Unit and ALARM*. Sept. 1999 (cit. on p. 103).

[Abt1970] Clark C Abt. *Serious Games*. The Vicking Press, 1970 (cit. on p. 39).

[Abt1987] Clark C Abt. *Serious games*. University Press of America, 1987 (cit. on p. 39).

[Adla2010] Abdelkader Adla. "Aide à la Facilitation pour une prise de Décision Collective: Proposition d'un Modèle et d'un Outil". PhD thesis. Université Paul Sabatier-Toulouse III, 2010 (cit. on p. 77).

[Adla+2007] Abdelkader Adla, Jean-Luc Soubie, and Pascale Zarate. "A co-operative intelligent decision support system for boilers combustion management based on a distributed architecture". In: *Journal of decision Systems* 16.2 (2007), pp. 241–263 (cit. on p. 77).

[Agency2016] European Aviation Safety Agency. *Annual Safety Review*. Tech. rep. 2016, p. 96 (cit. on p. 5).

[Aleven+2009] Vincent Aleven, Bruce M Mclaren, Jonathan Sewall, and Kenneth R Koedinger "A new paradigm for intelligent tutoring systems: Example-tracing tutors". In: *International Journal of Artificial Intelligence in Education* 19.2 (2009), pp. 105–154 (cit. on pp. 85, 160).

[Alinier+2008] Guillaume Alinier, Colin Harwood, Pat Harwood, Sue Montague, Eileen Huish, and Krishna Ruparelia. *Development of a programme to facilitate interprofessional simulation-based training for final year undergraduate healthcare students*. Tech. rep. Higher Education Academy/University of Hertfordshire, 2008 (cit. on pp. 21, 24).

[Allweyer2010] T. Allweyer. *BPMN 2.0: Introduction to the Standard for Business Process Modeling*. BoD–Books on Demand, 2010 (cit. on p. 51).

[Alter+1980] Steven Alter and Steven Alter. *Decision support systems: current practice and continuing challenges*. Tech. rep. 1980 (cit. on p. 76).

[Alvarez2007] Julian Alvarez. "Du jeu vidéo au serious game, approches culturelles, pragmatique et formelle". PhD thesis. Université Toulouse-Le Mirail, 2007 (cit. on p. 39).

[Amalberti+2005] René Amalberti, Yves Auroy, Don Berwick, and Paul Barach. “Five system barriers to achieving ultrasafe health care”. In: *Annals of internal medicine* 142.9 (2005), pp. 756–764 (cit. on pp. 4, 6).

[Amokrane+2008] Kahina Amokrane, Domitile Lourdeaux, and Jean-Marie Burkhardt. “HERA: Learner Tracking in a Virtual Environment.” In: *IJVR* 7.3 (2008), pp. 23–30 (cit. on pp. 47, 87, 161).

[Anderson+1997] John R Anderson, Michael Matessa, and Christian Lebiere. “ACT-R: A theory of higher level cognition and its relation to visual attention”. In: *Human-Computer Interaction* 12.4 (1997), pp. 439–462 (cit. on p. 160).

[Apperley2006] Thomas H Apperley. “Genre and game studies: Toward a critical approach to video game genres”. In: *Simulation & Gaming* 37.1 (2006), pp. 6–23 (cit. on p. 40).

[Atak+2011] Ahmet Atak and Sytze Kingma. “Safety culture in an aircraft maintenance organisation: A view from the inside”. In: *Safety science* 49.2 (2011), pp. 268–278 (cit. on p. 5).

[Authority2002] Civil Aviation Authority. *CAP 720: Flight crew training: Cockpit resource management (CRM) and line-oriented flight training (LOFT)*. London: CAA Safety Regulation Group, 2002 (cit. on pp. 21, 23).

[Authority2012] Pennsylvania Patient Safety Authority. *Pennsylvania Patient Safety Authority - 2012*. Annual report 2012. Pennsylvania, 2012, p. 19 (cit. on pp. 28, 177).

[Baker2003] Michael Baker. “Computer-mediated argumentative interactions for the co-elaboration of scientific notions”. In: *Arguing to learn*. Springer, 2003, pp. 47–78 (cit. on p. 80).

[Baker+1999] Michael Baker, Erica De Vries, and Kristine Lund. “Designing computer-mediated epistemic interactions”. In: *AIED’99: 9th International Conference on Artificial Intelligence in Education*. IOS Press, 1999, pp. 139–146 (cit. on p. 80).

[Barot+2013] Camille Barot, Domitile Lourdeaux, J-M Burkhardt, Kahina Amokrane, and Dominique Lenne. “V3S: A virtual environment for risk-management training based on human-activity models”. In: *Presence: Teleoperators and Virtual Environments* 22.1 (2013), pp. 1–19 (cit. on pp. 47, 88, 161).

[Baydogan+2009] Emre Baydogan, Lee A Belfore, Mark Scerbo II, and Saurav Mazumdar. “Virtual Operating Room Team Training via Computer–Based Agents”. In: *International Journal of Intelligent Control and Systems* 14.1 (2009), pp. 115–122 (cit. on p. 61).

[Beal+2006] Carole R Beal, Lei Qu, and Hyokyeong Lee. “Classifying learner engagement through integration of multiple data sources”. In: *Proceedings of the National Conference on Artificial Intelligence*. Vol. 21. Menlo Park, CA; Cambridge, MA; London; AAAI Press; MIT Press; 1999, 2006, p. 151 (cit. on p. 89).

[Beck2005] Joseph Beck. “Engagement tracing: using response times to model student disengagement”. In: *Artificial intelligence in education: Supporting learning through intelligent and socially informed technology* 125 (2005), p. 88 (cit. on p. 85).

[Bell+2008] Bradford S Bell, Adam M Kanar, and Steve WJ Kozlowski. “Current issues and future directions in simulation-based training in North America”. In: *The International Journal of Human Resource Management* 19.8 (2008), pp. 1416–1434 (cit. on p. 13).

[Bellotti+2010] Francesco Bellotti, Riccardo Berta, Alessandro De Gloria, and Ludovica Primavera. “Supporting authors in the development of task-based learning in serious virtual worlds”. In: *British Journal of Educational Technology* 41.1 (2010), pp. 86–107 (cit. on p. 51).

[BenchCapon2002] Trevor Bench-Capon. “Value based argumentation frameworks”. In: *arXiv preprint cs/0207059* (2002) (cit. on p. 75).

[Bergeron2006] Bryan Bergeron. “Developing serious games (game development series)”. In: (2006) (cit. on p. 40).

[Besnard+2014] Philippe Besnard, Alejandro Garcia, Anthony Hunter, Sanjay Modgil, Henry Prakken, Guillermo Simari, and Francesca Toni. “Introduction to structured argumentation”. In: *Argument & Computation* 5.1 (Jan. 2014), pp. 1–4 (cit. on p. 75).

[Besnard+2008] Philippe Besnard and Anthony Hunter. *Elements of argumentation*. Vol. 47. MIT press Cambridge, 2008 (cit. on p. 75).

[Biddle+1966] Bruce J Thomas Biddle and J Edwin. *Role theory: Concepts and research.* Tech. rep. 1966 (cit. on p. 116).

[BinSubaih+2009] Ahmed BinSubaih, Steve Maddock, and Daniela Romano. “Developing a serious game for police training”. In: *Handbook of research on effective electronic gaming in education*. IGI Global, 2009, pp. 451–477 (cit. on p. 101).

[Bird1974] F Bird. *Management guide to loss control*. Atlanta GA: Institute Press, 1974 (cit. on p. 4).

[Boeing2015] Boeing. *Statistical summary of commercial jet airplane accidents: Worldwide operations*. Tech. rep. Boeing, 2015, p. 26 (cit. on p. 5).

[Boet+2013] Sylvain Boet, M Dylan Bould, Bharat Sharma, Scott Revees, Viren N Naik, Emmanuel Triby, and Teodor Grantcharov. “Within-team debriefing versus instructor-led debriefing for simulation-based education: a randomized controlled trial”. In: *Annals of surgery* 258.1 (2013), pp. 53–58 (cit. on p. 170).

[Bonczek+1981] Robert H. Bonczek, Clyde W. Holsapple, and Andrew B. Whinston. *Foundations of Decision Support Systems*. en. Academic Press, 1981 (cit. on p. 76).

[Bosser+2010] Anne-Gwenn Bosser, MO Cavazza, and Ronan Champagnat. “Linear logic for non-linear storytelling”. In: IOS Press, 2010 (cit. on p. 50).

[Bouvier+2013] Patrice Bouvier, Elise Lavoué, Karim Sehaba, and Sébastien George. “Identifying Learner’s Engagement in Learning Games: A Qualitative Approach based on Learner’s Traces of Interaction”. In: *5th International Conference on Computer Supported Education (CSEDU 2013)*. 2013, pp. 339–350 (cit. on p. 89).

[Bovo2014] Angela Bovo. “Apprentissage automatique pour l’assistance au suivi d’étudiants en ligne : approches classique et bio-inspirée”. en. Thèse. Dec. 2014 (cit. on p. 89).

[Brehmer1992] Berndt Brehmer. “Dynamic decision making: Human control of complex systems”. In: *Acta psychologica* 81.3 (1992), pp. 211–241 (cit. on pp. 72, 74).

[Bristol2004] N. D. Bristol. “Shared mental models: conceptualisation and measurement”. PhD thesis. University of Nottingham: School of Mechanical, Materials and Manufacturing Engineering, 2004 (cit. on p. 7).

[Brom+2007] Cyril Brom, Vít Šisler, and Tomáš Holan. “Story Manager in ‘Europe 2045 ‘Uses Petri Nets”. In: *International Conference on Virtual Storytelling*. Springer, 2007, pp. 38–50 (cit. on p. 49).

[Brown2011] M Brown. *Learning analytics: The coming third wave (EDUCAUSE Learning Initiative Brief)*. Retrieved from EDUCAUSE library https://net. educause. edu/ir/library/pdf/ELIB1101. pdf, 2011 (cit. on p. 88).

[Bureau1996] Australian Transportation Safety Bureau. *Human Factors in Fatal Aircraft Accidents*. Bureau of Air Safety Investigation. Australia, 1996 (cit. on p. 6).

[Burenheide2007] Brad Burenheide. “Using wargames in the classroom to teach historical thought”. In: *Teaching History: A Journal of Methods* 32.1 (2007), pp. 18–27 (cit. on p. 78).

[Burke+2004] CS Burke, Eduardo Salas, K Wilson-Donnelly, and H Priest. “How to turn a team of experts into an expert medical team: guidance from the aviation and military communities”. In: *Quality and Safety in Health Care* 13.suppl 1 (2004), pp. i96–i104 (cit. on pp. 170, 171).

[Busemann+2012] Alexandra Busemann and Claus-Dieter Heidecke. “Safety Checklists in the Operating Room”. In: *Deutsches Arzteblatt International* 109.42 (Oct. 2012), pp. 693–694 (cit. on pp. 29, 177).

[Capin+1997] Tolga K Capin, Hansrudi Noser, Daniel Thalmann, Igor Sunday Pandzic, and Nadia Magnenat Thalmann. “Virtual human representation and communication in VLNet”. In: *IEEE Computer Graphics and Applications* 2 (1997), pp. 42–53 (cit. on p. 36).

[Carayon2006] Pascale Carayon. “Human factors of complex sociotechnical systems”. In: *Applied ergonomics* 37.4 (2006), pp. 525–535 (cit. on pp. 9, 27).
[Carpentier+2013] Kevin Carpentier and Domitile Lourdeaux. “Generation of learning situations according to the learner’s profile within a virtual environment”. In: *International Conference on Agents and Artificial Intelligence*. Springer, 2013, pp. 245–260 (cit. on pp. 47, 87, 88).
[Carthey+2011] Jane Carthey, Susannah Walker, Vashist Deelchand, Charles Vincent, and William Harrop Griffiths. “Breaking the rules: understanding non-compliance with policies and guidelines”. In: *BMJ-British Medical Journal* 343.3 (2011), p. d5283 (cit. on p. 10).
[Cassell2000] Justine Cassell. *Embodied conversational agents*. MIT press, 2000 (cit. on pp. 57, 59).
[Chatti+2012] Mohamed Amine Chatti, Anna Lea Dyckhoff, Ulrik Schroeder, and Hendrik Thüs. “A reference model for learning analytics”. In: *International Journal of Technology Enhanced Learning* 4.5-6 (2012), pp. 318–331 (cit. on p. 88).
[Chin+2009] Tat-Jun Chin, Yilun You, Celine Coutrix, Joo-Hwee Lim, Jean-Pierre Chevallet, and Laurence Nigay. “Mobile phone-based mixed reality: Snap2Play game”. In: Visual Computer 25.1 (2009), pp. 25–37 (cit. on p. 15).
[Chokshi+2014] Apoorve Chokshi, Teddy Seyed, Francisco Marinho Rodrigues, and Frank Maurer. “ePlan Multi-Surface: A Multi-Surface Environment for Emergency Response Planning Exercises”. In: *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*. ITS ’14. New York, NY, USA: ACM, 2014, pp. 219–228 (cit. on p. 78).
[Clawson+1993] Victoria K Clawson, Robert P Bostrom, and Rob Anson. “The role of the facilitator in computer-supported meetings”. In: *Small Group Research* 24.4 (1993), pp. 547–565 (cit. on p. 77).
[Cobb+2008] SC Cobb, Mirabelle D’Cruz, Andrew Day, Philippe David, Frédéric Gardeux, EL Broek, MC Voort, Frank Meijer, José Luis Izkara, and Dimitris Mavrikios. “How is VR used to support training in industry? The INTUITION network of excellence working group on education and training”. In: (2008) (cit. on p. 22).
[Collé+2005] Frédéric Collé, Ronan Champagnat, and Armelle Prigent. “Scenario analysis based on linear logic”. In: *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology*. ACM, 2005, p. 1 (cit. on p. 49).
[Conati2002] Cristina Conati. “Probabilistic assessment of user’s emotions in educational games”. In: *Applied artificial intelligence* 16.7-8 (2002), pp. 555–575 (cit. on p. 85).
[Conati+2002] Cristina Conati, Abigail Gertner, and Kurt Vanlehn. “Using Bayesian networks to manage uncertainty in student modeling”. In: *User modeling and user-adapted interaction* 12.4 (2002), pp. 371–417 (cit. on pp. 88, 161).
[Conati+2009] Cristina Conati and Heather Maclaren. “Empirically building and evaluating a probabilistic model of user affect”. In: *User Modeling and User-Adapted Interaction* 19.3 (2009), pp. 267–303 (cit. on p. 85).
[Cook+2009] David A Cook and Marc M Triola. “Virtual patients: a critical literature review and proposed next steps”. In: *Medical education* 43.4 (2009), pp. 303–311 (cit. on p. 17).
[Cornes2015] Dr Michelle Cornes. “Review of Interprofessional Education in the United Kingdom (1997–2013)”. In: *Journal of Interprofessional Care* 29.1 (Jan. 2015), pp. 85–85 (cit. on pp. 21, 23).
[Courtney+1993] James F Courtney and David B Paradice. “Studies in managerial problem formulation systems”. In: *Decision Support Systems* 9.4 (1993), pp. 413–423 (cit. on p. 76).
[Crichton+2004] MT Crichton and R Flin. “Identifying and training non-technical skills of nuclear emergency response teams”. In: *Annals of Nuclear Energy* 31.12 (2004), pp. 1317–1330 (cit. on pp. 21, 23, 101).

[Dang2013] Kim Dung Dang. “Aide à la réalisation de systèmes de pilotage de narration interactive : validation d’un scénario basée sur un modèle en logique linéaire”. fr. PhD thesis. Université de La Rochelle, Apr. 2013 (cit. on p. 50).

[Dang+2010] Kim Dang, Ronan Champagnat, and Michel Augeraud. “Modeling of interactive storytelling and validation of scenario by means of linear logic”. In: *Interactive Storytelling* (2010), pp. 153–164 (cit. on p. 50).

[DaylamaniZad+2016] Damon Daylamani-Zad, Marios C Angelides, and Harry Agius. “Lu-Lu: A framework for collaborative decision making games”. In: *Decision Support Systems* 85 (2016), pp. 49–61 (cit. on p. 79).

[Debouck+2012] F. Debouck, E. Rieger, H. Petit, G. Noël, and L. Ravinet. “[ORION®: a simple and effective method for systemic analysis of clinical events and precursors occurring in hospital practice]”. fre. In: *Cancer Radiothérapie: Journal De La Société Française De Radiothérapie Oncologique* 16.3 (May 2012), pp. 201–208 (cit. on p. 103).

[Degani+1993] Asaf Degani and Earl L Wiener. “Cockpit checklists: Concepts, design, and use”. In: *Human Factors: The Journal of the Human Factors and Ergonomics Society* 35.2 (1993), pp. 345–359 (cit. on p. 17).

[Devreux2015] Gilles Devreux. “Le rôle des comportements informationnels dans la prise de conscience de la situation : Usage dans le Serious Game 3D Virutal Operating Room. Thèse de doctorat en Psychologie, Université Jean Jaurès, Toulouse, France”. PhD thesis. France: Institut National Universitaire Champollion, 2015 (cit. on p. 105).

[Devreux+2014] Gilles Devreux, Géraldine Faure, Aline Chevalier, Julien Cegarra, Vincent Lubrano, and Thomas Rodsphon. “The role of expertise and team situation awareness in a dynamic system: the case of the operating room”. In: Paris, 2014 (cit. on pp. 30, 56, 105).

[Dieckmann+2009] Peter Dieckmann, Susanne Molin Friis, Anne Lippert, and Doris Østergaard. “The art and science of debriefing in simulation: Ideal and practice”. In: *Medical teacher* 31.7 (2009), e287–e294 (cit. on pp. 22, 25).

[Dillenbourg+2011] Pierre Dillenbourg and Michael Evans. “Interactive tabletops in education”. In: *International Journal of Computer-Supported Collaborative Learning* 6.4 (2011), pp. 491–514 (cit. on p. 81).

[2012] *Disney Stars : the virtual sell.* Serious game. 2012 (cit. on p. 61).

[Djaouti+2011] Damien Djaouti, Julian Alvarez, and Jean-Pierre Jessel. “Classifying serious games: the G/P/S model”. In: *Handbook of research on improving learning and motivation through educational games: Multidisciplinary approaches* 2 (2011), pp. 118–136 (cit. on p. 40).

[Dmello+2008] Sidney K D’mello, Scotty D Craig, Amy Witherspoon, Bethany Mcdaniel, and Arthur Graesser. “Automatic detection of learner’s affect from conversational cues”. In: *User modeling and user-adapted interaction* 18.1 (2008), pp. 45–80 (cit. on p. 85).

[Donaldson2009] L Donaldson. “Safer medical practice: machines, manikins and polo mints”. In: *150 years of the annual report of the chief medical officer: on the state of the public health 2008* (2009), pp. 49–55 (cit. on pp. 21, 24).

[Duncan Jr1973] Starkey Duncan Jr. “Toward a grammar for dyadic conversation”. In: *Semiotica* 9.1 (1973), pp. 29–46 (cit. on p. 64).

[Dung1995] Phan Minh Dung. “On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games”. In: *Artificial intelligence* 77.2 (1995), pp. 321–357 (cit. on p. 75).

[Duranti1997] Alessandro Duranti. *Linguistic Anthropology.* 0 edition. Cambridge University Press, 1997 (cit. on p. 64).

[Duval2011] Erik Duval. “Attention please!: learning analytics for visualization and recommendation”. In: *Proceedings of the 1st international conference on learning analytics and knowledge.* ACM, 2011, pp. 9–17 (cit. on p. 89).

[Edward+2008] Lydie Edward, Domitile Lourdeaux, Jean-Paul A Barthès, Dominique Lenne, and Jean-Marie Burkhardt. “Modelling autonomous virtual agent behaviours in a virtual environment for risk.” In: *IJVR* 7.3 (2008), pp. 13–22 (cit. on pp. 47, 82, 101).

[Effken2002] Judith A Effken. “Different lenses, improved outcomes: a new approach to the analysis and design of healthcare information systems”. In: *International journal of medical informatics* 65.1 (2002), pp. 59–74 (cit. on pp. 9, 27).

[Egges+2007] Arjan Egges, George Papagiannakis, and Nadia Magnenat-Thalmann. “Presence and interaction in mixed reality environments”. In: *Visual Computer* 23.5 (May 2007), pp 317–333 (cit. on p. 36).

[Elrod+1992] Scott Elrod, Richard Bruce, Rich Gold, David Goldberg, Frank Halasz, William Janssen, David Lee, Kim McCall, Elin Pedersen, Ken Pier, et al. “Liveboard: a large interactive display supporting group meetings, presentations, and remote collaboration”. In: *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 1992, pp. 599–607 (cit. on p. 35).

[Elverdam+2007] Christian Elverdam and Espen Aarseth. “Game classification and game design: Construction through critical analysis”. In: *Games and Culture* 2.1 (2007), pp. 3–22 (cit. on p. 40).

[Endsley1995] Mica R. Endsley. “Toward a theory of situation awareness in dynamic systems”. In: Human Factors 37.1 (1995), pp 32–64 (cit. on pp. 30, 56).

[Endsley+2000] Mica R. Endsley and Michelle M. Robertson. “Situation awareness in aircraft maintenance teams”. In: *International Journal of Industrial Ergonomics* 26.2 (2000), pp. 301–325 (cit. on p. 6).

[Evagorou+2012] Maria Evagorou, Maria Pilar Jimenez-Aleixandre, and Jonathan Osborne. “"Should We Kill the Grey Squirrels?" A Study Exploring Students’ Justifications and Decision-Making”. In: *International Journal of Science Education* 34.3 (2012), pp. 401–428 (cit. on p. 82).

[Fanning+2007] Ruth M Fanning and David M Gaba. “The role of debriefing in simulation-based learning”. In: *Simulation in healthcare* 2.2 (2007), pp. 115–125 (cit. on pp. 22, 24).

[Fischler+2008] Ira S Fischler, Cynthia E Kaschub, David E Lizdas, and Samsun Lampotang. “Understanding of anesthesia machine function is enhanced with a transparent reality simulation”. In: *Simulation in Healthcare* 3.1 (2008), pp. 26–32 (cit. on p. 17).

[Fiske+2007] Susan T Fiske, Amy JC Cuddy, and Peter Glick. “Universal dimensions of social cognition: Warmth and competence”. In: *Trends in cognitive sciences* 11.2 (2007), pp. 77–83 (cit. on p. 56).

[Flin+2010] R Flin, R Patey, R Glavin, and N Maran. “Anaesthetists’ non-technical skills”. In: *British journal of anaesthesia* 105.1 (2010), pp. 38–44 (cit. on p. 30).

[Fortin+2009] Tony Fortin and Laurent Tremel. *Mythologie des jeux vidéo*. Myth’o. Cavalier Bleu Eds, 2009 (cit. on p. 39).

[Foundation2000] “ALAR (Approach and Landing Accident Reduction) - Briefing Note 2-1 – Human factors”. In: Flight Safety Digest (Nov. 2000). Ed. by Flight Safety Foundation (cit. on p. 6).

[Fracker1990] M. L. Fracker. “Attention gradients in situation awareness. In situational Awareness in Aerospace Operations”. In: Neuilly Sur Seine France : Nato-Agard, 1990, pp 6/1–6/10 (cit. on p. 6).

[Frank+2002] Geoffrey Frank, Curry Guinn, Robert Hubal, Pamela Pope, Martha Stanford, and Deborah Lamm-Weisel. “Just-talk: An application of responsive virtual human technology”. In: *Proceedings of the Interservice/Industry Training, Simulation and Education Conference*. Citeseer, 2002, pp. 773–779 (cit. on pp. 60, 101).

[Fraser1997] Norman Fraser. “Assessment of Interactive Systems. Handbook on Standards and Resources for Spoken Language Systems.” In: Berlin, Mouton de Gruyter, 1997, pp. 564–615 (cit. on p. 65).

[Fraser+1991] Norman M. Fraser and G. Nigel Gilbert. “Simulating Speech systems”. In: *Computer Speech & Language*. Elsevier 5.Issue 1 (Jan. 1991), pp. 81–99 (cit. on p. 65).

[Freese+2015] Maria Freese and Sebastian Drees. “D-CITE-A Serious Game to Analyze Complex Decision-Making in Air Traffic Management”. In: *International Conference on Games and Learning Alliance*. Springer, 2015, pp. 23–31 (cit. on p. 79).

[Fried+2010] Marvin P Fried, Babak Sadoughi, Marc J Gibber, Joseph B Jacobs, Richard A Lebowitz, Douglas A Ross, John P Bent III, Sanjay R Parikh, Clarence T Sasaki, and Steven D Schaefer. “From virtual reality to the operating room: the endoscopic sinus surgery simulator experiment”. In: *Otolaryngology—Head and Neck Surgery* 142.2 (2010), pp. 202–207 (cit. on p. 17).

[Fudickar+2012] Axel Fudickar, Kim Hörle, Jörg Wiltfang, and Berthold Bein. “The Effect of the WHO Surgical Safety Checklist on Complication Rate and Communication”. In: *Deutsches Ärzteblatt International* 109.42 (Oct. 2012), pp. 695–701 (cit. on p. 30).

[Gaba2000] David M Gaba. “Structural and organizational issues in patient safety: a comparison of health care to other high-hazard industries”. In: *California Management Review* 43.1 (2000), pp. 83–102 (cit. on p. 6).

[Gaba+2001] David M Gaba, Steven K Howard, Kevin J Fish, Brian E Smith, and Yasser A Sowb. “Simulation-based training in anesthesia crisis resource management (ACRM): a decade of experience”. In: *Simulation & Gaming* 32.2 (2001), pp. 175–193 (cit. on p. 101).

[Gaba2004] DM Gaba. “The future vision of simulation in health care.” In: *PubMed* 13 Suppl 1:i2-10. (Oct. 2004) (cit. on p. 16).

[Galaup+2015] Michel Galaup, Frédéric Segonds, Catherine Lelardeux, and Pierre Lagarrigue. “Mecagenius : An Innovative Learning Game for Mechanical Engineering.” In: *International Journal of Engineering Education* 31.3 (2015), pp. 786–797 (cit. on p. 46).

[Gallagher+2005] Anthony G Gallagher, E Matt Ritter, Howard Champion, Gerald Higgins, Marvin P Fried, Gerald Moses, C Daniel Smith, and Richard M Satava. “Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training”. In: *Annals of surgery* 241.2 (2005), pp. 364–372 (cit. on pp. 16, 17).

[Gawande+1999] Atul A Gawande, Eric J Thomas, Michael J Zinner, and Troyen A Brennan. “The incidence and nature of surgical adverse events in Colorado and Utah in 1992”. In: *Surgery* 126.1 (1999), pp. 66–75 (cit. on pp. 7, 31).

[Gerbaud2008] Stéphanie Gerbaud. “Contribution à la formation en réalité virtuelle : scénarios collaboratifs et intégration d’humains virtuels collaborant avec des utilisateurs réels”. Theses. INSA de Rennes, Oct. 2008 (cit. on pp. 37, 116).

[Gerbaud+2007] Stéphanie Gerbaud, Nicolas Mollet, and Bruno Arnaldi. “Virtual Environments for Training: From Individual Learning to Collaboration with Humanoids”. In: *Edutainment*. Hong-Kong, Hong Kong SAR China, 2007 (cit. on p. 101).

[Gibson1978] James J. Gibson. “The Ecological Approach to the Visual Perception of Pictures”. In: *Leonardo* 11.3 (1978), pp. 227–235 (cit. on pp. 36, 109, 116).

[Gleeson+2015] S. Gleeson, P. Groom, and S. Mercer. “Human factors in complex airway management”. en. In: *BJA Education* (Sept. 2015), mkv045 (cit. on p. 31).

[Gleicher+2011] Michael Gleicher, Danielle Albers, Rick Walker, Ilir Jusufi, Charles D Hansen, and Jonathan C Roberts. “Visual comparison for information visualization”. In: *Information Visualization* 10.4 (2011), pp. 289–309 (cit. on p. 89).

[Glendon2009] Ian A Glendon. “Multimodal safety management and human factors: Crossing the borders of medical, aviation, road and rail industries”. In: (2009) (cit. on p. 4).

[Göbel+2009] Stefan Göbel, Florian Mehm, Sabrina Radke, and Ralf Steinmetz. “80days: Adaptive digital storytelling for digital educational games”. In: *Proceedings of the 2nd International Workshop on Story-Telling and Educational Games (STEG’09)*. Vol. 498. 2009 (cit. on p. 48).

[Goodwin1981] Charles Goodwin. *Conversational organization: Interaction between speakers and hearers*. Academic Press, 1981 (cit. on p. 64).

[Gordon+2005] Frances Gordon and Claire Walsh. "A framework for interprofessional capability: Developing students of health and social care as collaborative workers". In: *Journal of Integrated Care* 13.3 (2005), pp. 26–33 (cit. on pp. 21, 23).

[Gough+2012] Suzanne Gough, Mark Hellaby, Neal Jones, and Ralph MacKinnon. "A review of undergraduate interprofessional simulation-based education (IPSE)". In: *Collegian*. Special Issue : Clinical Simulation 19.3 (2012), pp. 153–170 (cit. on pp. 21, 23).

[Govaerts+2012] Sten Govaerts, Katrien Verbert, Erik Duval, and Abelardo Pardo. "The student activity meter for awareness and self-reflection". In: *CHI'12 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2012, pp. 869–884 (cit. on pp. 88, 89).

[Granry+2012] Jean-Claude Granry and Marie-Christine Moll. *Etat de l'art en matière de pratiques de simulation dans le domaine de la santé*. Tech. rep. France: Haute Autorité de Santé, 2012, p. 110 (cit. on pp. 21, 23, 31).

[Grant+1992] Janet Grant and Philip Marsden. *Training senior house officers by service-based learning*. Joint Centre for Education in Medicine London, 1992 (cit. on p. 170).

[Greller+2012] Wolfgang Greller and Hendrik Drachsler. "Translating learning into numbers: A generic framework for learning analytics." In: *Educational technology & society* 15.3 (2012), pp. 42–57 (cit. on p. 88).

[Grice+1975] H Paul Grice, Peter Cole, and Jerry L Morgan. "Syntax and semantics". In: *Logic and conversation* 3 (1975), pp. 41–58 (cit. on p. 64).

[Grossi+2013] Davide Grossi and Wiebe Van Der Hoek. "Audience-Based Uncertainty in Abstract Argument Games." In: *IJCAI*. Vol. 13. 2013, pp. 143–149 (cit. on p. 75).

[Guo+2014] Jing Guo, Nicolas Singer, and Rémi Bastide. "A Serious Game Engine for Interview Simulation: Application to the development of doctor-patient communication". In: *International Conference on Games and Virtual Worlds for Serious Applications - VS-GAMES 2014*. Malta, Malta, Sept. 2014, pp. 1–6 (cit. on p. 58).

[GuyeVuillème+1999] Anthony Guye-Vuillème, Tolga K Capin, S Pandzic, N Magnenat Thalmann, and Daniel Thalmann. "Nonverbal communication interface for collaborative virtual environments". In: *Virtual Reality* 4.1 (1999), pp. 49–59 (cit. on p. 60).

[Hall2016] Joseph Lorenzo Hall. "Columbia and Challenger: organizational failure at NASA". In: *Space Policy* 37 (2016), pp. 127–133 (cit. on p. 102).

[Halverson+2011] Amy L. Halverson, Jessica T. Casey, Jennifer Andersson, Karen Anderson, Christine Park, Alfred Rademaker, and Don Moorman. "Communication failure in the operating room". In: *Surgery* 149.3 (Mar. 2011), pp. 305–310 (cit. on pp. 7, 21, 23, 28, 31).

[Harousseau2012] Jean-Luc Harousseau. *La sécurité des patients Mettre en œuvre la gestion des risques associés aux soins en établissement de santé - Des concepts à la pratique*. National Report. France: Haute Autorité de Santé (HAS), 2012 (cit. on p. 12).

[Hartel+1989] CEJ Hartel, KA Smith, and C Prince. "Defining aircrew coordination: Searching mishaps for meaning". In: *Fifth International Symposium on Aviation Psychology*. UQ Business School Publications. Columbus, OH, United States: Ohio State University, 1989 (cit. on p. 6).

[Hauge+2012] Jannicke Baalsrud Hauge, Gabriele Hoeborn, and Jennifer Bredtmann. "Challenges of serious games for improving students' management skills on decision making". In: *Handbook of research on serious games as educational, business and research tools: development and design, IGI global* (2012), pp. 947–964 (cit. on p. 79).

[Haynes+2009] Alex B. Haynes, Thomas G. Weiser, William R. Berry, Stuart R. Lipsitz, Abdel-Hadi S. Breizat, E. Patchen Dellinger, Teodoro Herbosa, Sudhir Joseph, Pascience L. Kibatala, Marie Carmela M. Lapitan, Alan F. Merry, Krishna Moorthy, Richard K. Reznick, Bryce Taylor, Atul A. Gawande, and Safe Surgery Saves Lives Study Group. "A surgical safety checklist to reduce morbidity and mortality in a global population".

eng. In: *The New England Journal of Medicine* 360.5 (Jan. 2009), pp. 491–499 (cit. on p. 29).

[Hays+2012] Robert T Hays and Michael J Singer. *Simulation fidelity in training system design: Bridging the gap between reality and training.* Springer Science & Business Media, 2012 (cit. on p. 13).

[Heinrich+1931] H Heinrich, D Peterson, and N Roos. *Industrial accident prevention: A safety management approach.* 1st ed. New York: Mc Graw Hill, 1931 (cit. on p. 4).

[Heinrich+2011] Stefan Heinrich and Stefan Wermter. "Towards robust speech recognition for human-robot interaction". In: *Proceedings of the IROS2011 Workshop on Cognitive Neuroscience Robotics (CNR).* 2011, pp. 29–34 (cit. on p. 60).

[Heinrichs+2008] William LeRoy Heinrichs, Patricia Youngblood, Phillip M. Harter, and Parvati Dev. "Simulation for Team Training and Assessment: Case Studies of Online Training with Virtual Worlds". en. In: *World Journal of Surgery* 32.2 (Feb. 2008), pp. 161–170 (cit. on p. 61).

[Hempel+2013] Susanne Hempel, Melinda Maggard Gibbons, David Nguyen, Aaron J. Dawes, Isomi M. Miake-Lye, Jessica M. Beroes, Roberta Shanman, and Paul G. Shekelle. *Prevention of Wrong Site Surgery, Retained Surgical Items, and Surgical Fires: A Systematic Review.* eng. VA Evidence-based Synthesis Program Reports. Washington (DC): Department of Veterans Affairs, 2013 (cit. on pp. 6, 7, 28, 31).

[Hennigan2012] Brad Hennigan. "Making the Case for NLP in Dialogue Systems for Serious Games". In: *8th International Conference on Natural Language Processing (JapTAL), 1st Workshop on Games and NLP* (2012) (cit. on p. 59).

[Herring1999] Susan Herring. "Interactional Coherence in CMC". In: *Journal of Computer-Mediated Communication* 4.4 (1999) (cit. on p. 66).

[Hertzog+2014] Thomas Hertzog, Jean-Christophe Poussin, Bréhima Tangara, Indé Kouriba, and Jean-Yves Jamin. "A role playing game to address future water management issues in a large irrigated system: Experience from Mali". In: *Agricultural water management* 137 (2014), pp. 1–14 (cit. on p. 80).

[Higgins+2012] Steve Higgins, Emma Mercier, Liz Burd, and Andrew Joyce-Gibbons. "Multi-touch tables and collaborative learning". In: *British Journal of Educational Technology* 43.6 (2012), pp. 1041–1054 (cit. on p. 81).

[Hoc+2007] Jean-Michel Hoc and René Amalberti. "Cognitive control dynamics for reaching a satisficing performance in complex dynamic situations". In: *Journal of Cognitive Engineering and Decision Making* 1.1 (2007), pp. 22–55 (cit. on p. 8).

[Hollnagel2004] Erik Hollnagel. "Barriers and accident prevention". In: (2004) (cit. on p. 4).

[Hollnagel+2012] Erik Hollnagel, David D. Woods, and Nancy Leveson. *Resilience Engineering: concept and precepts*. Ashgate Publishing Limited. 2012 (cit. on p. 11).

[Hubal+2004] Robert Hubal, Geoffrey Frank, Curry Guinn, and Randy Dupont. "Integrating a Crisis Stages Model into a Simulation for Training Law Enforcement Officers to Manage Encounters with the Mentally Ill (PDF Download Available)". In: *ResearchGate* (2004) (cit. on p. 60).

[Hulst+2012] AH van der Hulst and M Ruijsendaal. "Serious gaming for complex decision making". In: *1st International Workshop on Pedagogically-Driven Serious Games 2012, PDSG 2012-In Conjunction with the 7th European Conference on Technology Enhanced Learning.* Aachen, Sept. 2012, pp. 898, 51–60 (cit. on p. 79).

[Interactive2016] Succubus Interactive. *Serious Talk*. 2016 (cit. on p. 48).

[Isenberg1986] Daniel J Isenberg. "Group polarization: A critical review and meta-analysis." In: *Journal of personality and social psychology* 50.6 (1986), p. 1141 (cit. on p. 76).

[Isotani+2008] Seiji Isotani and Riichiro Mizoguchi. "Theory-Driven Group Formation through Ontologies". In: *Intelligent Tutoring Systems.* Springer, 2008, pp. 646–655 (cit. on p. 85).

[Jehn1995] Karen A Jehn. "A multimethod examination of the benefits and detriments of intragroup conflict". In: *Administrative science quarterly* (1995), pp. 256–282 (cit. on pp. 73, 74).

[Jehn1997] Karen A Jehn. "A qualitative analysis of conflict types and dimensions in organizational groups". In: *Administrative science quarterly* (1997), pp. 530–557 (cit. on p. 74).

[Jehn+2001] Karen A Jehn and Elizabeth A Mannix. "The dynamic nature of conflict: A longitudinal study of intragroup conflict and group performance". In: *Academy of management journal* 44.2 (2001), pp. 238–251 (cit. on p. 74).

[Johanson+2002] Brad Johanson, Armando Fox, and Terry Winograd. "The interactive workspaces project: Experiences with ubiquitous computing rooms". In: *IEEE pervasive computing* 1.2 (2002), pp. 67–74 (cit. on p. 35).

[Johnson+2008] Mary T. Johnson and Magistra Clary. "A Second Life Virtual Clinic For Medical Student Training". Second Life Education Community Conference (SLEDcc'08). 2008 (cit. on p. 63).

[Johnson2007] W Lewis Johnson. "Serious use of a serious game for language learning". In: *Frontiers in Artificial Intelligence and Applications* 158 (2007), p. 67 (cit. on p. 85).

[Johnson+2000] W Lewis Johnson, Jeff W Rickel, James C Lester, et al. "Animated pedagogical agents: Face-to-face interaction in interactive learning environments". In: *International Journal of Artificial intelligence in education* 11.1 (2000), pp. 47–78 (cit. on pp. 57, 58).

[Joint Aviation Autorities2017] Training Organisation Joint Aviation Autorities. *Training courses : Introduction to Accident and Incident Investigation Training Course*. 2017 (cit. on p. 17).

[Joint Commission2008] Joint Commission. *Improving America's Hospitals: The Joint Commission's Annual Report on Quality and Safety*. Vol. 25. Retreived February. 2008 (cit. on pp. 7, 28).

[Jorna+2007] Rene Jorna, Derk Jan Kiewiet, JR Wilson, B Norris, T Clarke, and A Mills. "Planning, reasoning and patterns of inferences: An empirical study into the reasoning of staff planners in the Netherlands railways". In: *People and rail systems: Human factors at the heart of the railway* (2007), pp. 287–299 (cit. on p. 7).

[Kaber+1998] David B. Kaber and Mica R. Endsley. "Team Situation Awareness for Process Control Safety and Performance". In: *Process Safety Progress* 17.1 (1998), pp. 43–48 (cit. on pp. 30, 56).

[Kaczmarczyk+2015] Joseph Kaczmarczyk, Richard Davidson, Daniele Bryden, Stephen Haselden, and Pirashanthie Vivekananda-Schmidt. "Learning decision making through serious games". In: *The clinical teacher* (2015) (cit. on p. 79).

[Kallmann+2002] Marcelo Kallmann and Daniel Thalmann. "Modeling behaviors of interactive objects for real-time virtual environments". In: *Journal of Visual Languages & Computing* 13.2 (2002), pp. 177–195 (cit. on p. 36).

[Karacapilidis+2001] Nikos Karacapilidis and Dimitris Papadias. "Computer supported argumentation and collaborative decision making: the HERMES system". In: *Information systems* 26.4 (2001), pp. 259–277 (cit. on p. 79).

[Keen+1978] Peter GW Keen, MichaelS Scott, et al. *Decisión support systems; an organizational perspective*. Tech. rep. 1978 (cit. on p. 72).

[Keyton+2010a] Joann Keyton and Stephenson J. Beck. "Perspective: examining communication as macrocognition in STS." In: *Human Factors: The Journal of the Human Factors and Ergonomics Society* 52.2 (Apr. 2010), pp. 335–339 (cit. on pp. 30, 55).

[Keyton+2010b] Joann Keyton, Stephenson J. Beck, and M. B. Asbury. "Macrocognition a communication perspective". In: *Taylor & Francis*. Theoretical Issues in Ergonomics Science 11.4 (2010), pp. 272–286 (cit. on pp. 30, 55).

[Kharrufa+2010] Ahmed Kharrufa, David Leat, and Patrick Olivier. "Digital mysteries: designing for learning at the tabletop". In: *ACM International Conference on Interactive Tabletops and Surfaces*. ACM, 2010, pp. 197–206 (cit. on p. 81).

[Kiewiet+2005] Derk J Kiewiet, René J Jorna, and Wout v Wezel. "Planners and their cognitive maps: An analysis of domain representations using multi dimensional scaling". In: *Applied ergonomics* 36.6 (2005), pp. 695–708 (cit. on p. 7).

[Kinkade+1972] R. G. Kinkade and G. R. Wheaton. "Human engineering guide to equipment design". In: *Human engineering guide to equipment design*. H. Vancoff & R. Kinkade Editions. Washington, DC: American Institutes for Research, 1972, pp. 667–699 (cit. on p. 13).

[Kohn+2000] Linda T. Kohn, Janet M. Corrigan, and Molla S. Donaldson, eds. *To err is Human: Building a Safer Health System*. Washington, D.C.: National Academies Press, 2000 (cit. on pp. 6, 7, 28, 31).

[Kolb1984] David A Kolb. *Experiential learning: Experience as the source of learning and development*. Pearson Education, 1984 (cit. on pp. 13, 24, 170).

[Kopp+2004] Stefan Kopp and Ipke Wachsmuth. "Synthesizing multimodal utterances for conversational agents". In: *Computer animation and virtual worlds* 15.1 (2004), pp. 39–52 (cit. on p. 36).

[Kraemer+1988] Kenneth L Kraemer and John Leslie King. "Computer-based systems for cooperative work and group decision making". In: *ACM Computing Surveys (CSUR)* 20.2 (1988), pp. 115–146 (cit. on p. 76).

[Laborie+2005] François Laborie, Stéphane Chatty, and Claude Reyterou. "Coordination and collaboration environments for production lines: a user acceptance issue". In: *ECSCW 2005*. Springer, 2005, pp. 407–426 (cit. on p. 35).

[Lave+1991] Jean Lave and Etienne Wenger. *Situated learning: Legitimate peripheral participation*. Cambridge university press, 1991 (cit. on p. 109).

[Leape+2005] L. L. Leape and D. M. Berwick. "Five years after To Err Is Human: what have we learned?" In: *Jama* 293.19 (2005), pp. 2384–2390 (cit. on p. 103).

[Leape1994] Lucian L Leape. "Error in medicine". In: *Jama* 272.23 (1994), pp. 1851–1857 (cit. on p. 6).

[Leckie+1996] Gloria J Leckie, Karen E Pettigrew, and Christian Sylvain. "Modeling the information seeking of professionals: a general model derived from research on engineers, health care professionals, and lawyers". In: *The Library Quarterly* (1996), pp. 161–193 (cit. on p. 135).

[Leelawong+2008] Krittaya Leelawong and Gautam Biswas. "Designing learning by teaching agents: The Betty's Brain system". In: *International Journal of Artificial Intelligence in Education* 18.3 (2008), pp. 181–208 (cit. on p. 85).

[Lemaitre+2015a] Juliette Lemaitre, Domitile Lourdeaux, and Caroline Chopinaud. "Towards a resource-based model of strategy to help designing opponent AI in RTS games". In: *7th International Conference on Agents and Artificial Intelligence (ICAART 2015)*. Vol. 1. ICAART 2015 - 7th International Conference on Agents and Artificial Intelligence. Lisbonne, Portugal, Jan. 2015, pp. 210–215 (cit. on p. 50).

[Lemaitre+2015b] Juliette Lemaitre, Domitile Lourdeaux, and Caroline Chopinaud. "Vers un modèle de stratégie basé sur la gestion des ressources pour la création des IA dans les RTS". In: *Treizièmes Rencontres des Jeunes Chercheurs en Intelligence Artificielle (RJCIA 2015)*. Rennes, France, June 2015 (cit. on p. 50).

[Liarokapis+2009] Fotis Liarokapis, Louis Macan, Gary Malone, Genaro Rebolledo-Mendez, and Sara de Freitas. "Multimodal augmented reality tangible gaming". en. In: *The Visual Computer* 25.12 (Aug. 2009), pp. 1109–1120 (cit. on p. 15).

[Lingard+2004] L. Lingard, S. Espin, S. Whyte, G Regehr, G Baker, and R Reznick. "Communication failure in the operating room : Observational classification of reccurent types and effects". In: *Quality and safety in heathcare* 13.5 (2004), pp. 330–334 (cit. on pp. 7, 28, 31).

[Link+2006] Michael W Link, Polly P Armsby, Robert C Hubal, and Curry I Guinn. "Accessibility and acceptance of responsive virtual human technology as a survey interviewer training tool". In: *Computers in Human Behavior* 22.3 (2006), pp. 412–426 (cit. on p. 60).

[Linn+2004] Marcia C Linn, Philip Bell, and Elizabeth A Davis. "Specific design principles: Elaborating the scaffolded knowledge integration framework". In: *Internet environments for science education* (2004), pp. 315–340 (cit. on p. 81).

[Lipovic2011] I Lipovic. "Speech and Language Technologies". In: *InTech Open Access Publisher* (2011) (cit. on p. 65).

[Liu+2015] Min Liu, Jina Kang, Jaejin Lee, Elena Winzeler, and Sa Liu. "Examining through visualization what tools learners access as they play a serious game for middle school science". In: *Serious Games Analytics*. Springer, 2015, pp. 181–208 (cit. on p. 89).

[Loh+2015] Christian Sebastian Loh, Yanyan Sheng, and Dirk Ifenthaler. "Serious games analytics: Theoretical framework". In: *Serious games analytics*. Springer, 2015, pp. 3–29 (cit. on p. 89).

[Lopez+2014] Thomas Lopez, Pierre Chevaillier, Valérie Gouranton, Paul Evrard, Florian Nouviale, Mukesh Barange, Rozenn Bouville Berthelot, and Bruno Arnaldi. "Collaborative Virtual Training with Physical and Communicative Autonomous Agents". In: *Computer Animation and Virtual Worlds* (2014), pp. 1–9 (cit. on p. 63).

[Lynch+2008] Collin Lynch, Niels Pinkwart, Kevin Ashley, and Vincent Aleven. "What do argument diagrams tell us about students' aptitude or experience? a statistical analysis in an ill-defined domain". In: *Intelligent Tutoring Systems for Ill-Defined Domains: Assessment and Feedback in Ill-Defined Domains.* (2008), p. 56 (cit. on p. 85).

[Ma+2004] Jiyong Ma and Ronald Cole. "Animating visible speech and facial expressions". en. In: *The Visual Computer* 20.2-3 (Mar. 2004), pp. 86–105 (cit. on p. 36).

[Malakis+2010] Stathis Malakis, Tom Kontogiannis, and Barry Kirwan. "Managing emergencies and abnormal situations in air traffic control (part I): Taskwork strategies". In: *Applied ergonomics* 41.4 (2010), pp. 620–627 (cit. on p. 4).

[Manske+2005] Micheline Manske and Cristina Conati. "Modelling Learning in an Educational Game." In: *AIED*. Vol. 2005. 2005, pp. 411–418 (cit. on p. 85).

[Marakas2003] George M Marakas. *Decision support systems in the 21st century*. Vol. 134. Prentice Hall Upper Saddle River, NJ, 2003 (cit. on p. 71).

[Markenson+2005] David Markenson, Charles DiMaggio, and Irwin Redlener. "Preparing health professions students for terrorism, disaster, and public health emergencies: core competencies". In: *Academic Medicine* 80.6 (2005), pp. 517–526 (cit. on p. 101).

[Martens+2013] Chris Martens, Anne-Gwenn Bosser, Joao F Ferreira, and Marc Cavazza. "Linear logic programming for narrative generation". In: *International Conference on Logic Programming and Nonmonotonic Reasoning*. Springer, 2013, pp. 427–432 (cit. on p. 50).

[Mateas+2004] M. Mateas and A. Stern. "Natural Language Understanding in Façade: Surfacetext Processing". In: *Proceedings of the Conference on Technologies for Interactive Digital Storytelling and Entertainment (TIDSE)* (2004) (cit. on pp. 58, 59).

[Mateas2002] Michael Mateas. "Interactive drama, art and artificial intelligence". In: (2002) (cit. on p. 58).

[Mateas+2003] Michael Mateas and Andrew Stern. "Integrating plot, character and natural language processing in the interactive drama Façade". In: *Proceedings of the 1st International Conference on Technologies for Interactive Digital Storytelling and Entertainment (TIDSE-03)*. Vol. 2. 2003 (cit. on p. 58).

[Mathieu+2000] John E Mathieu, Tonia S Heffner, Gerald F Goodwin, Eduardo Salas, and Janis A Cannon-Bowers. "The influence of shared mental models on team process and performance." In: *Journal of applied psychology* 85.2 (2000), p. 273 (cit. on pp. 30, 56).

[Mathieu+2012] Philippe Mathieu, David Panzoli, and SÃ©bastien Picault. "Virtual customers in an Agent World". In: *10th international conference on Practical Application *of Agent and Multi-Agent Systems (PAAMS'12)*. Vol. 155. University of Salamanca, Spain, Mar. 2012, pp. 147–152 (cit. on p. 51).

[McDermott+1998] Drew McDermott, Malik Ghallab, Adele Howe, Craig Knoblock, Ashwin Ram, Manuela Veloso, Daniel Weld, and David Wilkins. "PDDL-the planning domain definition language". In: (1998) (cit. on p. 50).

[McDonald+2000] Noreen McDonald, Siobhan Corrigan, Colin Daly, and Sam Cromie. "Safety management systems and safety culture in aircraft maintenance organisations". In: *Safety Science* 34.1 (2000), pp. 151–176 (cit. on p. 5).

[McGrath1984] Joseph Edward McGrath. *Groups: Interaction and performance*. Vol. 14. Prentice-Hall Englewood Cliffs, NJ, 1984 (cit. on p. 38).

[Mercier2009] Hugo Mercier. "La théorie argumentative du raisonnement". PhD thesis. France: ECOLE DES HAUTES ETUDES EN SCIENCES SOCIALES, 2009 (cit. on p. 74).

[Michael+2005] David R Michael and Sandra L Chen. *Serious games: Games that educate, train, and inform*. Muska & Lipman/Premier-Trade, 2005 (cit. on pp. 39, 40).

[Mirzaei+2013] Mohammad Reza Mirzaei, Seyed Ghorshi, and Mohammad Mortazavi. "Audio-visual speech recognition techniques in augmented reality environments". In: *The Visual Computer* 30.3 (2013), pp. 245–257 (cit. on p. 65).

[Monden2011] Yasuhiro Monden. *Toyota production system: an integrated approach to just-in-time*. CRC Press, 2011 (cit. on p. 35).

[Morningstar+1990] Chip Morningstar and Randall F. Farmer. "The Lessons of Lucasfilm's Habitat". In: *The First International Conference on Cyberspace*. Ed. by Michael Benedikt. University of Texas at Austin, 1990 (cit. on pp. 36, 63).

[Morton1971] Scott Morton. *Management decision systems, computer based support for decision making*. Harvard University. Boston, USA, 1971 (cit. on p. 72).

[MotyMonnereau2009] Céline Moty-Monnereau. *ENEIS : Enquête nationale de mesure des évènements indésirables graves*. Tech. rep. French National heathcare ministry, 2009 (cit. on p. 6).

[Murphy+2007] JG Murphy, F Cremonini, GC Kane, and W Dunn. "Is simulation based medicine training the future of clinical medicine?" In: *European review for medical and pharmacological sciences* 11.1 (2007), p. 1 (cit. on p. 16).

[Murphy2001] Philippa Murphy. "The role of communications in accidents and incidents during rail possessions". In: *Engineering Psychology and Cognitive Ergonomics Volume Five. Aerospace and Transportation Systems. Aldershot, Ashgate* (2001), pp. 447–454 (cit. on p. 7).

[Natkin+2003] Stéphane Natkin and Liliana Vega. "A petri net model for the analysis of the ordering of actions in computer games". In: *GAME ON 2003*. 2003 (cit. on p. 49).

[Natkin+2004] Stéphane Natkin, Liliana Vega, and S Grünvogel. "A new methodology for spatiotemporal game design". In: *Mehdi, Q. and Gough, N.,(Eds.). Proceedings of CGAIDE 2004, 5th Game-On International Conference on Computer Games: Artificial Intelligence, Design and Education*. 2004, pp. 109–113 (cit. on p. 49).

[Navarathna+2010] Rajitha Navarathna, Patrick Lucey, David Dean, Clinton Fookes, and Sridha Sridharan. "Lip detection for audio-visual speech recognition in-car environment". In: *Proc. of the 10th International Conference on Information Science, Signal Processing and Their Applications*. IEEE, 2010, pp. 598–601 (cit. on p. 65).

[Norman1991] Donald A Norman. "Cognitive artifacts". In: *Designing interaction: Psychology at the human-computer interface* 1 (1991), pp. 17–38 (cit. on p. 110).

[Norros+1999] Leena Norros and Ulla-Maija Klemola. "Methodological considerations in analysing anaesthetists' habits of action in clinical situations". In: *Ergonomics* 42.11 (1999), pp. 1521–1530 (cit. on p. 30).

[Nunamaker Jr+1996] Jay F Nunamaker Jr, Robert O Briggs, Daniel D Mittleman, Douglas R Vogel, and Balthazard A Pierre. "Lessons from a dozen years of group support systems research: A discussion of lab and field findings". In: *Journal of management information systems* 13.3 (1996), pp. 163–207 (cit. on p. 77).

[Obrenović2011] Željko Obrenović. "Design-based research: what we learn when we engage in design of interactive systems". In: *interactions* 18.5 (2011), pp. 56–59 (cit. on pp. 126, 133).

[Ohlsson1994] Stellan Ohlsson. "Constraint-based student modeling". In: *Student modelling: the key to individualized knowledge-based instruction*. Springer, 1994, pp. 167–189 (cit. on p. 161).

[Orkin+2007] J. Orkin and D. Roy. "The restaurant game: Learning social behavior and language from thousands of players online". In: *Journal of Game Development* 3.1 (2007), pp. 39–60 (cit. on p. 51).

[Pandzic+1999] Igor S. Pandzic, Jörn Ostermann, and David Millen. "User evaluation: Synthetic talking faces for interactive services". In: *The Visual Computer* 15.7 (Nov. 1999), pp. 330–340 (cit. on p. 57).

[Park+2015] Yeonjeong Park and Il-Hyun Jo. "Development of the Learning Analytics Dashboard to Support Students' Learning Performance." In: *J. UCS* 21.1 (2015), pp. 110–133 (cit. on p. 88).

[Parvati+2011] DEV Parvati and W LeRoy Heinrichs. "CliniSpace™: A Multiperson 3D Online Immersive Training Environment Accessible through a Browser". In: *Medicine Meets Virtual Reality 18: NextMed* 163 (2011), p. 173 (cit. on p. 63).

[Patient Safety2009] World Alliance for Patient Safety, ed. *WHO Surgical Safety Checklist*. 2009 (cit. on pp. 12, 28, 177).

[Pegden+1995] C Dennis Pegden, Randall P Sadowski, and Robert E Shannon. *Introduction to simulation using SIMAN*. McGraw-Hill, Inc., 1995 (cit. on p. 13).

[Pennsylvania Patient Safety Authority2007] Pennsylvania Patient Safety Authority. *Pennsylvania Patient Safety Authority - 2007*. Annual report. Pennsylvania, 2007, p. 51 (cit. on pp. 7, 28).

[Pickup+2005] Laura Pickup, John R Wilson, Sarah Sharpies, Beverley Norris, Theresa Clarke, and Mark S Young. "Fundamental examination of mental workload in the rail industry". In: *Theoretical issues in ergonomics science* 6.6 (2005), pp. 463–482 (cit. on p. 7).

[Plasters+2003] C. L. Plasters, F. J Seagull, and Y. Xiao. "Coordination challenges in operating-room management:an in-depth field study". In: *AMIA Annual Symposium Proceedings*. 2003 (cit. on pp. 7, 9, 28, 31).

[Plsek+2001] Paul E Plsek and Trisha Greenhalgh. "The challenge of complexity in health care". In: *British Medical Journal* 323.7313 (2001), p. 625 (cit. on pp. 9, 27).

[Pons Lelardeux+2015] Catherine Pons Lelardeux, Michel Galaup, Frédéric Segonds, and Pierre Lagarrigue. "Didactic study of a learning game to teach mechanical engineering". In: *The Manufacturing Engineering Society International Conference* Procedia Engineering.132 (2015), pp. 242–250 (cit. on p. 46).

[Pons Lelardeux+2016] Catherine Pons Lelardeux, David Panzoli, Vincent Lubrano, Vincent Minville, Pierre Lagarrigue, and Jean-Pierre Jessel. "Communication system and team situation awareness in a multiplayer real-time learning environment: application to a virtual operating room". In: *Visual Computer* in progress (2016) (cit. on p. 195).

[Porteous+2010] J. Porteous, M. Cavazza, and F. Charles. "Applying Planning to Interactive Storytelling: Narrative Control Using State Constraints". In: *ACM Trans. Intell. Syst. Technol.* 1.2 (2010), 10:1–10:21 (cit. on p. 48).

[Prigent+2007] Armelle Prigent, Ronan Champagnat, and Pascal Estraillier. "Exécution adaptative de trame narrative". In: *Intelligence artificielle et jeux*. Ed. by T. Cazenave. Hermès Sciences, 2007, pp. 155–180 (cit. on p. 49).

[Puentes2011] Antonio F. Puentes. "The manual flight skill of modern airline pilots". PhD thesis. USA: San Jose State University, Dec. 2011 (cit. on pp. 17, 101).

[Rall+2000] M. Rall, T. Manser, and S. K. Howard. "Key elements of debriefing for simulator training". en. In: *European Journal of Anaesthesiology* 17.8 (2000), pp. 516–517 (cit. on pp. 22, 25).

[Ramsey+1999] Matthew Ramsey and Nina Rattner Gelbart. *The King's Midwife: A History and Mystery of Madame du Coudray*. JSTOR, 1999 (cit. on p. 13).

[Rasmussen1983] Jens Rasmussen. "Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models". In: *IEEE transactions on systems, man, and cybernetics* 3 (1983), pp. 257–266 (cit. on p. 8).

[Rasmussen1997] Jens Rasmussen. "Risk management in a dynamic society: a modelling problem". In: *Safety science* 27.2 (1997), pp. 183–213 (cit. on pp. 38, 103).

[Rasmussen+1989] Jens Rasmussen and Kim J Vicente. "Coping with human errors through system design: implications for ecological interface design". In: *International Journal of Man-Machine Studies* 31.5 (1989), pp. 517–534 (cit. on p. 150).

[Raux+2007] M. Raux, M. Dupont, and J.-M. Devys. "[Systemic analysis using ALARM process of two consecutive incidents during anaesthesia]". fre. In: *Annales Francaises D'anesthesie Et De Reanimation* 26.9 (Sept. 2007), pp. 805–809 (cit. on p. 103).

[Reason1990] James Reason. *Human Error*. New York: Cambridge University Press, 1990 (cit. on p. 4).

[Reason2000] James Reason. "Human error: models and management". In: *British Medical Journal* 320.7237 (2000), pp. 768–770 (cit. on pp. 102, 171).

[Reason2013] James Reason. *A life in error*. Ashgate. Farnham:Ashgate Pub Ltd, 2013 (cit. on pp. 29, 102).

[Reddy+2006] Madhu Reddy and Jansen J. Bernard. "A model for understanding collaborative information behavior in context: A study of two healthcare teams". In: (2006) (cit. on p. 136).

[Reddy+2010] Madhu Reddy, Bernard Jansen, and Patricia Spence. "collaborative information behavior : Exploring Collaboration and coordination during information seeking and retrieval activities". In: *Collaborative Information Behavior: User Engagement and Communication sharing*. IGI Global. 2010 (cit. on p. 135).

[Reese+2010] Cynthia E Reese, Pamela R Jeffries, and Scott A Engum. "Learning together: Using simulations to develop nursing and medical student collaboration". In: *Nursing education perspectives* 31.1 (2010), pp. 33–37 (cit. on pp. 21, 23, 24).

[Riedl+2011] Mark Riedl, Boyang Li, Hua Ai, and Ashwin Ram. "Robust and Authorable Multiplayer Storytelling Experiences." In: *AIIDE*. 2011 (cit. on p. 48).

[Riem+2012] N Riem, S Boet, MD Bould, W Tavares, and VN Naik. "Do technical skills correlate with non-technical skills in crisis resource management: a simulation study". In: *British journal of anaesthesia* 109.5 (2012), pp. 723–728 (cit. on pp. 21, 23).

[Ritsos+2014] Panagiotis D Ritsos and Jonathan C Roberts. "Towards more visual analytics in learning analytics". In: *Proceedings of the 5th EuroVis Workshop on Visual Analytics*. 2014, pp. 61–65 (cit. on p. 89).

[Rogers+2017] Gary D Rogers, Jill E Thistlethwaite, Elizabeth S Anderson, Madeleine Abrandt Dahlgren, Ruby E Grymonpre, Monica Moran, and Dujeepa D Samarasekera. "International consensus statement on the assessment of interprofessional learning outcomes". In: *Medical teacher* 39.4 (2017), pp. 347–359 (cit. on pp. 21, 23).

[Rogers+2004] Yvonne Rogers and Siân Lindley. "Collaborating around vertical and horizontal large interactive displays: which way is best?" In: *Interacting with Computers* 16.6 (2004), pp. 1133–1152 (cit. on p. 81).

[Rosen2008] Kathleen R Rosen. "The history of medical simulation". In: *Journal of critical care* 23.2 (2008), pp. 157–166 (cit. on p. 16).

[Rus+2013] Vasile Rus, Sidney D'Mello, Xiangen Hu, and Arthur Graesser. "Recent Advances in Conversational Intelligent Tutoring Systems". In: *AI Magazine* 34.3 (2013), pp. 42–54 (cit. on p. 59).

[Sacks+1974] Harvey Sacks, Emanuel A Schegloff, and Gail Jefferson. "A simplest systematics for the organization of turn-taking for conversation". In: *language* (1974), pp. 696–735 (cit. on pp. 64, 74).

[Salas+2001] Eduardo Salas, C Shawn Burke, Clint A Bowers, and Katherine A Wilson. "Team training in the skies: does crew resource management (CRM) training work?" In: *Human Factors* 43.4 (2001), pp. 641–674 (cit. on pp. 21, 24).

[Salas+2011] Eduardo Salas, Stephen M. Fiore, and Michael Petsky. "Theories of Team Cognition: Cross-Disciplinary Perspectives". In: (2011) (cit. on pp. 22, 25).

[Salas+1995] Eduardo Salas, Carolyn Prince, Baker David, and Lisa Shrestha. "Situation awareness in team performance - Implications for measurment and training". In: Human Factors 37.1 (1995), pp. 123–136 (cit. on pp. 30, 100).

[Salas+2009] Eduardo Salas, Jessica L Wildman, and Ronald F Piccolo. "Using simulation-based training to enhance management education". In: *Academy of Management Learning & Education* 8.4 (2009), pp. 559–573 (cit. on p. 13).

[Sanchez+2004] Stephane Sanchez, Olivier Balet, Hervé Luga, and Yves Duthen. "Autonomous Virtual Actors". In: *2nd International Conference on Technologies for Interactive Digital Storytelling and Entertainment , Darmstadt, Germany, 24/06/2004-26/06/2004*. Springer Verlag LNCS, 2004, pp. 68–78 (cit. on p. 48).

[Sanselone+2014] Maxime Sanselone, Stephane Sanchez, Cédric Sanza, David Panzoli, and Yves Duthen. "Control of non-playing characters in a medical learning game with Monte Carlo Tree Search (regular paper)". anglais. In: *IEEE Conference on Computational Intelligence and Games*. Dortmund, Germany: IEEE Computer Society, 2014, pp. 208–215 (cit. on pp. 128, 130).

[Saraos Luna+2012] Andrés Saraos Luna, Valérie Gouranton, and Bruno Arnaldi. "Collaborative Virtual Environments For Training: A Unified Interaction Model For Real Humans And Virtual Humans". In: *International Conference on Serious Games and Edutainment*. Germany, 2012, pp. 1–12 (cit. on p. 63).

[Sarter+1991] Nadine B. Sarter and David D. Woods. "Situation awareness:A critical but ill-defined phenomenon". In: *International Journal of aviation psychology* 1.1 (1991), pp. 45–47 (cit. on p. 6).

[Satava1996] Richard M Satava. "Medical virtual reality. The current status of the future." In: *Studies in health technology and informatics* 29 (1996), p. 100 (cit. on p. 16).

[Savoldelli+2013] G Savoldelli and S Boet. "Séance de simulation: du briefing au débriefing". In: *La simulation en santé De la théorie à la pratique*. Springer, 2013, pp. 313–328 (cit. on p. 170).

[Sawyer2007] Ben Sawyer. "Serious games: Broadening games impact beyond entertainment". In: *Computer Graphics Forum*. Vol. 26. Wiley Online Library, 2007 (cit. on p. 39).

[Sawyer+2008] Ben Sawyer and Peter Smith. "Serious games taxonomy". In: *Slides from the Serious Games Summit at the Game Developers Conference*. 2008 (cit. on p. 40).

[Sebillotte+1994] Suzanne Sebillotte and Dominique L Scapin. "From users' task knowledge to high-level interface specification". In: *International Journal of Human-Computer Interaction* 6.1 (1994), pp. 1–15 (cit. on pp. 47, 88).

[Seiden+2006] Samuel C Seiden and Paul Barach. "Wrong-side/wrong-site, wrong-procedure, and wrong-patient adverse events: are they preventable?" In: *Archives of surgery* 141.9 (2006), pp. 931–939 (cit. on pp. 28, 177).

[Shanahan+2007] Paul Shanahan, Dik Gregory, Mike Shannon, and Huw Gibson. "The role of communication errors in railway incident causation". In: *People and rail systems—human factors at the heart of the railway. Ashgate* (2007), pp. 427–35 (cit. on p. 7).

[Shappell+2012] Scott A Shappell and Douglas A Wiegmann. *A human error approach to aviation accident analysis: The human factors analysis and classification system*. Ashgate Publishing, Ltd., 2012 (cit. on p. 4).

[Simon1965] Herbert Alexander Simon. *Administrative behavior*. Vol. 4. Cambridge Univ Press, 1965 (cit. on p. 74).

[Simons+2000] Tony L Simons and Randall S Peterson. "Task conflict and relationship conflict in top management teams: the pivotal role of intragroup trust." In: *Journal of applied psychology* 85.1 (2000), p. 102 (cit. on p. 73).

[Skjerve+2002] Ann Britt Skjerve, Johanna Ludvigsen, and Tore Neset. "Identification of qualifications for train-dispatcher trainees". In: (2002) (cit. on p. 7).

[Specht+1991] Linda B Specht and Petrea K Sandlin. "The differential effects of experiential learning activities and traditional lecture classes in accounting". In: *Simulation & Gaming* 22.2 (1991), pp. 196–210 (cit. on pp. 13, 24).

[Steiner1972] Ivan D Steiner. "Group Process and Productivity". In: Academic Press (1972) (cit. on p. 38).

[Sterman1989] John D Sterman. *Misperceptions of feedback in dynamic decision making*. Springer, 1989 (cit. on pp. 30, 78).

[Straeter+2002] Oliver Straeter and Barry Kirwan. "Differences between human reliability approaches in nuclear-and aviation-safety". In: *Human Factors and Power Plants, 2002. Proceedings of the 2002 IEEE 7th Conference on*. IEEE, 2002, pp. 3–39 (cit. on p. 4).

[Streitz+1999] Norbert A Streitz, Jörg Gei\s sler, Torsten Holmer, Shin'ichi Konomi, Christian Müller-Tomfelde, Wolfgang Reischl, Petra Rexroth, Peter Seitz, and Ralf Steinmetz. "i-LAND: an interactive landscape for creativity and innovation". In: *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM, 1999, pp. 120–127 (cit. on p. 35).

[Stytz+1996] Martin R Stytz, Brian W Garcia, Gayl M Godsell-Stytz, and Sheila B Banks. "A distributed virtual environment prototype for emergency medical procedures training." In: *Studies in health technology and informatics* 39 (1996), pp. 473–485 (cit. on p. 101).

[Susman+1986] Gerald I Susman and Richard B Chase. "A sociotechnical analysis of the integrated factory". In: *The Journal of Applied Behavioral Science* 22.3 (1986), pp. 257–270 (cit. on p. 8).

[Swartout+2006] William R Swartout, Jonathan Gratch, Randall W Hill Jr, Eduard Hovy, Stacy Marsella, Jeff Rickel, David Traum, et al. "Toward virtual humans". In: *AI Magazine* 27.2 (2006), p. 96 (cit. on pp. 60, 101).

[Szyld+2013] Demian Szyld and Jenny W. Rudolph. "Debriefing with Good Judgment". In: *The Comprehensive Textbook of Healthcare Simulation*. Ed. by Adam I. Levine, Samuel DeMaria, Andrew D. Schwartz, and Alan J. Sim. New York, NY: Springer New York, 2013, pp. 85–93 (cit. on pp. 159, 170).

[Taekman+2007] Jeffrey M Taekman, Noa Segall, E Hobbs, and Melanie Wright. "3DiTeams–Healthcare team training in a virtual environment". In: *Anesthesiology* 107.A2145 (2007), A2145 (cit. on p. 63).

[Tear2002] Michael F MC Tear. "Spoken Dialogue Technology : Enabling the Conversationnal User Interface". In: *ACM Computing Surveys*. Vol. 34. 1. Mar. 2002 (cit. on pp. 60, 65).

[Thomas+2000] Eric J Thomas, David M Studdert, Helen R Burstin, E John Orav, Timothy Zeena, Elliott J Williams, K Mason Howard, Paul C Weiler, and Troyen A Brennan. "Incidence and types of adverse events and negligent care in Utah and Colorado". In: *Medical care* (2000), pp. 261–271 (cit. on p. 6).

[Thomas+2012] Pradeepa Thomas, Jean-Marc Labat, Mathieu Muratet, and Amel Yessad. "How to Evaluate Competencies in Game-Based Learning Systems Automatically?" In: *11th international conference on Intelligent Tutoring Systems*. Vol. 7315. Lecture Notes in Computer Science. Chania, Greece: Springer, 2012, pp. 168–173 (cit. on pp. 49, 160).

[Thompson2013] Leigh L. Thompson. *Making the Team: a guide for Managers*. English. 5 edition. Pearson, July 2013 (cit. on pp. 72, 73).

[Tong+2017] Lili Tong, Audrey Serna, Sébastien George, and Aurélien Tabard. "Supporting Decision-making Activities in Multi-Surface Learning Environments". Mar. 2017 (cit. on p. 81).

[Trist1981] Eric Trist. “The evolution of socio-technical systems”. In: *Occasional paper* 2 (1981), p. 1981 (cit. on p. 8).

[Van Der Veer+1996] Gerrit C Van Der Veer, Bert F Lenting, and Bas AJ Bergevoet. “GTA: Groupware task analysis—Modeling complexity”. In: *Acta psychologica* 91.3 (1996), pp. 297–322 (cit. on pp. 47, 88).

[Vaughan2004] Diane Vaughan. “Theorizing disaster: Analogy, historical ethnography, and the Challenger accident”. In: *Ethnography* 5.3 (2004), pp. 315–347 (cit. on p. 102).

[Verbert+2014] Katrien Verbert, Sten Govaerts, Erik Duval, Jose Luis Santos, Frans Van Assche, Gonzalo Parra, and Joris Klerkx. “Learning dashboards: an overview and future research opportunities”. In: *Personal and Ubiquitous Computing* 18.6 (2014), pp. 1499–1514 (cit. on pp. 88, 89).

[Vicente1999] Kim J. Vicente. *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work*. en. CRC Press, 1999 (cit. on p. 9).

[Vincent2004] CA Vincent. “Analysis of clinical incidents: a window on the system not a search for root causes”. In: *Quality and Safety in Health Care* 13.4 (2004), pp. 242–243 (cit. on p. 103).

[Vincent+1998] Charles Vincent, Sally Taylor-Adams, and Nicola Stanhope. “Framework for analysing risk and safety in clinical medicine”. In: *Bmj* 316.7138 (1998), pp. 1154–1157 (cit. on pp. 104, 105).

[Vinokur1971] Amiram Vinokur. “Review and theoretical analysis of the effects of group processes upon individual and group decisions involving risk.” In: *Psychological Bulletin* 76.4 (1971), p. 231 (cit. on p. 76).

[Vinokur+1978] Amiram Vinokur and Eugene Burnstein. “Depolarization of attitudes in groups.” In: *Journal of Personality and Social Psychology* 36.8 (1978), p. 872 (cit. on p. 76).

[Walsh+2009] Catharine M Walsh, Simon C Ling, Charlie S Wang, and Heather Carnahan. “Concurrent versus terminal feedback: it may be better to wait”. In: *Academic Medicine* 84.10 (2009), S54–S57 (cit. on p. 170).

[Watkins+1998] Ryan Watkins, Doug Leigh, Rob Foshay, and Roger Kaufman. “Kirkpatrick plus: Evaluation and continuous improvement with a community focus”. In: *Educational Technology Research and Development* 46.4 (1998), pp. 90–96 (cit. on p. 42).

[Websky+2012] Martin W von Websky, Martina Vitz, Dimitri A Raptis, R Rosenthal, PA Clavien, and Dieter Hahnloser. “Basic laparoscopic training using the Simbionix LAP Mentor: setting the standards in the novice group”. In: *Journal of surgical education* 69.4 (2012), pp. 459–467 (cit. on p. 17).

[Weick1990] Karl E Weick. “The vulnerable system: An analysis of the Tenerife air disaster”. In: *Journal of management* 16.3 (1990), pp. 571–593 (cit. on p. 102).

[White2004] Stephen A White. “Introduction to BPMN”. In: *IBM Cooperation* 2.0 (2004) (cit. on pp. 51, 52).

[Whitehead1981] Bruce A. Whitehead. “James J. Gibson: The ecological approach to visual perception. Boston: Houghton Mifflin, 1979, 332 pp”. In: *Behavioral Science* 26.3 (1981), pp. 308–309 (cit. on p. 116).

[Wiegmann+2005] Douglas A Wiegmann, T Faaborg, A Boquet, C Detwiler, K Holcomb, and Scott A Shappell. *Human Error and General Aviation Accidents: A Comprehensive, Fine-Grained Analysis Using HFACS*. Tech. rep. Office of Aerospace Medicine Federal Aviation Administration. 2005 (cit. on p. 5).

[Wilson+2006] John R. Wilson and Beverley J. Norris. “Human factors in support of a successful railway: a review”. en. In: *Cognition, Technology & Work* 8.1 (Jan. 2006), pp. 4–14 (cit. on pp. 4, 7).

[Wright2000] K Wright. *A human factors approach to investigating signals passed at danger.* Tech. rep. Rail Safety and Standards Board Research Catalogue. 2000 (cit. on p. 7).

[Zegers+2011] Marieke Zegers, Martine C de Bruijne, Bertus de Keizer, Hanneke Merten, Peter P Groenewegen, Gerrit van der Wal, and Cordula Wagner. “The incidence, root-causes, and outcomes of adverse events in surgical units: implication for potential prevention strategies”. In: *Patient safety in surgery* 5.1 (2011) (cit. on pp. 6, 27, 31).

[Ziv+2003] Amitai Ziv, Paul Root Wolpe, Stephen D Small, and Shimon Glick. “Simulation-based medical education: an ethical imperative”. In: *Simulation in Healthcare* 78.8 (2003), pp. 252–256 (cit. on p. 16).

[Zyda2005] Michael Zyda. “From visual simulation to virtual reality to games”. In: *Computer* 38.9 (2005), pp. 25–32 (cit. on p. 40).