TO LOOK OR NOT TO LOOK:

A STUDY OF VISUALISATION SUPPORTS IN AN EDUCATIONAL BUSINESS GAME

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Enschede, July 2005.

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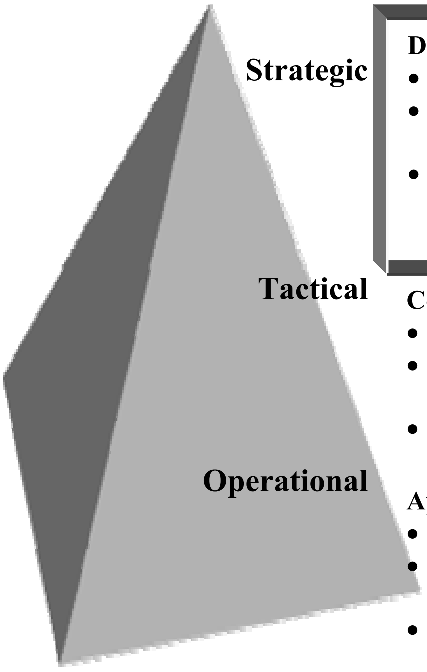
1 Introduction

1.1 The need to learn knowledge management

Since a couple of years, there has been a major shift from an industrial economy to a knowledge-based economy. This shift appears to cause changes in job characteristics in enterprises. Nowadays, jobs seem to be dominated by the need to innovate and the application of knowledge instead of by mainly using physical labour or capital (Boisot, 1998). Obviously, this shift has also consequences for the interaction between managers in an organisation.

The job characteristics in management, for instance, have changed. As the predicable and routine tasks, and processes that highly dominated the operational work will be more automated and transferred directly to the clients, managing will become more focused on managing knowledge. This work involves some combination of the predictable and the unpredictable, and the careers of those doing this, will increasingly move toward higher strategic levels (see the top of the pyramid in Figure 1-1). This strategic work is characterised by many decision-centred jobs and in this decision process people tend to be confronted with incomplete or inconsistent information. Analysing, perceiving, recalling, and performing are actions that are required to develop new strategies, which have led to a new paradigm of working in the knowledge-based economy. This situation drives a need to obtain more knowledge as organisational resources than other types of work. It is almost similar to what Wiig (1997) said: knowledge is a differentiating competitive factor for individuals, corporations, and nations.



Decision-centred Work.

- Primary actions are to perceive, recall, and perform.
- Managers deal with new problem situations and with incomplete and inconsistent information.
- Decision support is required to enable assimilation analysis of information, and development of new strategies.

Context-centred Work.

- Primary actions are to perceive, recall, and perform.
- Managers must combine different tasks; they recognise context and select appropriate tactics.
- Functional support is required.

Application-centred Work.

- Primary actions are to perceive and perform.
- Managers perform fixed procedures and repetitive actions.
- Screen-based support is required

Figure 1-1. The work pyramid (Winslow & Bramer, 1994).

Another consequence of the shift to more strategic work is that the problems encountered are new, more diverse, complex, and their solution involves different agents. Cross functional team emerged, rewards and recognition shifted from being based on individual performance to being based on team performance, team performance was often rated higher than individual accomplishment (Junnarkar, 1997). Moreover, self-directed work teams are also seen as an important mechanism for dealing with today's complex and rapid changing environment (Hitchcock & Willard, 1995). However, the drawback is that the interaction of agents with different backgrounds and expertise adds to the complexity of the work. Therefore, knowledge about how to work together with others to benefit from knowledge as an organisational resource is required in modern enterprises. We believe that knowledge management (KM) will be able to provide knowledge how to deal with a diversity of people in decision-centred collaborative jobs.

From what is said above, it is already obvious that a new way of thinking and interacting is necessary to deal with the lack of information, the fuzziness, and the complexity of strategic work. Senge (1990) stated that managers in enterprises require changes in their sense of "how to think" and "how to interact" to deal with the complexity of new situations. He introduced the term of "the learning organisation" which can be defined as an organisation that is continually expanding its capacity to create its future. He believes that incorporating the learning process in the working environment is needed, to continuously develop new strategies and to possess knowledge about the organisational resources at every moment through thinking and interacting.

The question is how should managers learn? It is generally accepted that without a proper conceptual model that underlies and shapes the process of developing and utilising knowledge in an organisation, learning processes in an organisation will not occur. A potentially powerful answer to this question is to introduce the manager to knowledge management as a new conceptual approach for the perspective of a learning organisation. In other words, trying to capitalize on the positive properties of knowledge as the most valuable organisational resource which are non-rivalness and growth through use, can provide managers with a new way of thinking in the knowledge economy.

Wiig (1995) defines knowledge management (KM) as "a conceptual framework that encompasses all activities and perspectives required to gaining an overview of, creating, dealing with, and benefiting from the corporation's business and operations". The goal of KM is to make the enterprise act as intelligently as possible and realise the best value from its knowledge asset (Wiig, De Hoog, & Van der Spek, 1997). Sveiby (2001) defines a so called "people-track" of KM which is equal to management of people and which sees knowledge as processes of a complex set of dynamic skills, know-how etcetera, that is constantly changing. He said also that with the decreasing interest in ICT lately, the people track has attracted more attention. This addresses an issue about how to maximise the ability of an organisation to create new knowledge and how to build an environment that contributes to sharing of knowledge.

Introducing knowledge management, as proposed above, seems to fit the problem of the new job's task and interaction requirements described. However, in reality many problems are encountered when implementing this idea in an organisation. Understanding and realising this new paradigm of thinking and interacting through KM as the conceptual model, requires a broader and ongoing research effort for two main reasons: first, the concept of KM itself does not offer direct and pragmatic solutions to decision-based problems in organisations; second, understanding KM as conceptual knowledge from a working perspective is itself a knowledge intensive tasks that requires complex interaction between managers. These two factors explain why *learning* KM and *doing* KM activities in the actual working situation must be investigated further. The aim of this dissertation is to contribute research findings to the development of KM activities by combining learning and doing perspectives.

1.2 Focus of the current study

The solution of the general problem statement described in the previous section is, primarily, by offering knowledge management as a domain to be learned in a realistic situation that is very similar to the work context. One of its unique characteristics is its collaborative nature.

In this dissertation, the context of the study can be stated briefly as follows: “learning KM *in* a collaborative activity”. The italicized “in” emphasises that KM is learned as a new domain but at the same time the process of learning KM itself is offered as a knowledge intensive activity. Thus, KM not only fulfils a need to learn a new domain that might provide a valuable conceptual framework for dealing with the new work paradigm, but at the same time requires managers to become involved in knowledge intensive activities that constitute the learning process. Both can supply rich and reflective learning opportunities to build generic KM problem-solving skills.

The focus of this dissertation is rather distinct, because KM is not only seen as a new domain that managers have to learn, but also as a process of KM activities to deal with the complexity of interactions between managers. Learning KM has become the target of understanding KM as a knowledge intensive task and as a valuable process in daily work, reflecting the complexity of the interactions among actors. The stance adopted in this dissertation is a blending between KM as conceptual knowledge as well as an activity in an organisation which is focused on the interaction between people involved in knowledge-intensive activities. In reality this phenomenon also occurs, hence KM is not considered as an isolated domain being learned, but performing KM activities during learning KM itself consists of many operational knowledge-intensive tasks, such as problem-solving and decision-making in organisational management activities. It means that understanding KM as generic knowledge and skills would not be achieved successfully without being involved in the knowledge intensive activities in collaborative work settings. This focus is indeed very similar to the main idea of the learning organisation, which sees that learning tasks, as a reflective and realistic activity, are the main elements of organisational learning activities.

Pragmatically, learning KM collaboratively may serve managers in two ways: first, by providing opportunities for managers to build a generic model of problem-solving skills based on KM conceptual knowledge, second, by situating managers in an organisational setting where knowledge intensive tasks have to be done by applying KM procedures. It is expected that in the context where learning knowledge management through collaborative learning takes place, it may give rich opportunities to the manager about what kind of conceptual framework they should use to approach problems in decision-based work and how to approach the problems collectively and meaningfully by means of being actively involved in knowledge-intensive activities. The benefit of offering learning KM as a knowledge intensive task is that it puts managers or learners into a realistic situation where KM problems may occur. The actual geographical dispersion of managers, which may threaten the process of solving problems collaboratively, is an example of a situation where a manager has to learn KM and apply KM as a strategy to solve the problem but at the same time he/she has to solve this problem collaboratively with other managers which are not on the spot. Thus, applying KM may be best achieved by providing the actual KM situation during the learning process of KM.

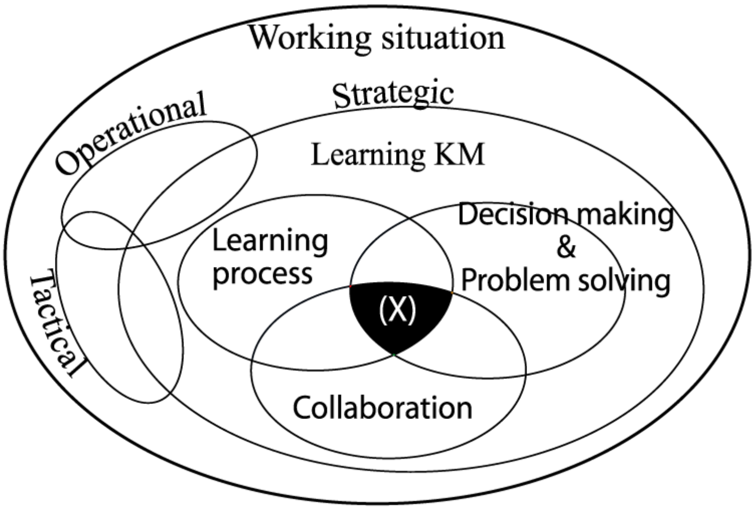


Figure 1-2. Context of this dissertation.

Figure 1-2 presents the context of this dissertation. Within this context we focus particularly on the intersection of the learning process, decision making and problem solving process, and collaboration (see the symbol (X) in the figure), which is seen as a dynamic process involving complex human interactions in learning (thinking) and work situations (interacting). It becomes obvious that learning KM through three sub-activities: learning, decision making and problem solving, and collaboration, can be seen as a knowledge-intensive task itself.

1.3 Narrowing the focus of the study: the research problems

Refining the focus of the research in this dissertation, special attention is given to investigate communication processes that occur in a situation similar to what can be expected in learning organisations. Communication between knowledge-actors plays a very crucial role in performing both KM activities and learning KM. The modalities of the medium of communication between the knowledge-actors are believed to determine, at least partly, the successfulness of performing KM intensive tasks, and as a consequence, learning. However, the way people communicate has changed lately. Face-to-face communication has been decreasing because it is costing much time and resources (Dennis & Kinney, 1998). Forms of mediated communication are on the increase.

As an illustration, given the current developments in information and communication technology (ICT), physical and geographical limitations to interactions between managers are not seen as obstacles anymore. It is now easier and faster to communicate across geographical boundaries than before. The presence of mediated communication in an enterprise as a backbone of daily activities, has become part and parcel of major managerial decision-centred work. The consequence is that there are many options to carry out simple and complex decision-centred work through mediated communication and with different communication modalities as compared to face-to-face interactions only. Thus it becomes obvious that as a knowledge manager, people will be dealing with mediated communication to do their daily job, and there is a tendency that knowledge managers will be confronted with communication processes in which the bandwidth may be limited.

This might be the main reason that lately computer mediated communication (CMC) such as chat systems, video conferencing systems, electronic discussion boards, and instant messaging systems to support synchronous communication seem to receive more attention than before in organisational research and development. A topic of great interest is to find technologically oriented communication tools, such as computer mediated communication tools, to “replace” direct (synchronous) face-to-face meeting cost effectively. The cost-effectiveness approach means that the mediated communication, given its limitations, is able to facilitate the task reasonably well. For instance, text-based internet chat, which is considered to be a narrow-bandwidth communication medium, is very easy to use, simple to be implemented on any platform, and very popular among Internet users due to its capability to transfer spontaneous-natural communication streams such as occurring in face-to-face communication. Less research has been done so far to investigate the effectiveness of a text-based chat system while solving complex problems or mediating communication of knowledge-intensive tasks interactions.

CMC serves the problem statement in this dissertation in two ways. First, CMC contributes to the realism of the learning situation, which requires learning to master the new domain and at the same time experiencing KM and communication problems. Second, CMC used in a knowledge-intensive activity provides explicit and accessible information on how people make decision or solve fuzzy problems (in this case, KM problems). The latter is clearly methodological, as logging CMC exchanges provides a convenient way to get insight into processes which in face-to-face communication require cumbersome procedures for recording and analysing.

For the focus of this study two theories are of foremost importance to explain the possible consequences of computer mediated communicative interaction when performing knowledge intensive activities: (1) traditional theories of communication and other mediated interactions, such as the “media richness theory” (Daft, Lengel, & Trevino, 1987; Daft & Wiginton, 1979), claim that despite the cost-effectiveness of a narrow-bandwidth communication medium, it has significant limitations to facilitate multi-focal tasks such as complex group decision making and problem solving processes; (2) information exchange theory that suggests that in general the goal of communication is to distribute information, conditioning information processing and analysing and evaluating actions collaboratively. This theory may suggest that the communication interaction in collaboration and making sense of the information being transferred through the communication medium, depends on how the information can be transferred in the medium and how human cognition can process the information. The media richness theory seems to predict that meaningful collaborative interactions to achieve shared ideas, to make joint decisions or to solve problems, such as in knowledge-intensive tasks, are difficult to realise if a narrow-bandwidth is used. However, the media richness theory does not take into account a particular important factor: the richness of the information presented in the environment and transmitted to the human cognitive system which has the ability to select and process the information. Interestingly, Propp (1999) mentioned clearly that the concept of information processing actually integrates both cognitive and communication processes. Thus, there should be a research effort to extend the theory of mediated communication and cognitive information processing for the collaborative activity of performing and learning knowledge-intensive tasks.

Theoretically, there is a strong need to investigate to what extent a narrow-bandwidth medium can be used in complex group interactions and how far such complex interactions can be implemented technologically in order to support the learning and performing of a knowledge intensive work task. This research is not only interesting from the perspective of mediated communication alone, but also to explore implementation of KM as a methodology in collaborative knowledge intensive activities.

Summarising, the assumptions listed below are at the basis of the research reported in this dissertation:

- Strategic decisions to solve complex problems will be dominating decision-centred work;
- Managers in decision-centred jobs often work collaboratively, involving various backgrounds and expertise;
- Learning and working should be performed jointly in an organisation;
- Learning KM is required to give managers with strategic problem solving and decision skills a way to deal with the complexity of decision-centred work;
- Group- or team-based interaction in learning and working in the context of learning KM should be present in order to make the process of learning KM more close to reality (transfer);
- The development of computer mediated communication will influence the interaction of managers in decision-centred jobs;
- Narrow bandwidth CMC has limitations for mediating complex interactions during group problem-solving and decision making, such as in knowledge-intensive activities: performing and learning KM;

- Narrow bandwidth computer mediated interactions between members of a group should be supported with objects or devices that facilitate knowledge-intensive tasks by easing the assimilation of the analysis of information, which is expected to occur when developing new strategies or solving problems.

The general discussion has thus been narrowed to the research problem as follows:

> "How to support information exchanges between people in narrow-bandwidth computer mediated communication while they perform complex problem solving and decision making activities that characterise knowledge-intensive tasks?"

This dissertation is mainly focused on the role of text-based CMC, such as in text-based internet chat, representing the narrow-bandwidth CMC. It is expected that answers on the research question will benefit research that aims to support collaborative interactions in narrow bandwidth CMC modes and as well as bridging the gulf between learning and working in knowledge intensive organisations.

In the context of CMC, the computer as a medium of communication has also an important function to present multimedia cues that moderate multi-focal information in computer-to-users and user-to-user exchanges, for example in presenting textual and visual information. It is generally accepted that textual information is better understood or becomes more meaningful if it is combined with visual cues. With the help of visual information we can develop more understanding of problems, generate more ideas, and promote the sharing of spatial information which is hardly possible by textual media. Thus, technologically it is always possible that when narrow-bandwidth (text-based) CMC is being used, support can be given to the users by means of displaying high quality visual information that is related to the goal of the interaction, for example by means of map, charts, or other graphical representations. It is expected that collaborative interactions can than produce better ideas and lead to better information sharing in problem-solving and decision making, hence promoting the learning process. However, only limited evidence can be found that explains or shows the function of visual information in collaborative interaction. The research done in this dissertation is designed to contribute to the research findings in this area.

There are many types of visual information with different types of information representations such as depicted by an image, an illustration, a map, charts, graphs, diagrams, and even spreadsheet tables. One important factor that specifies the type of visual representation is the type of information displayed and the abstraction level of the information. We focus on the visualisation of numerical information that may present different types of information abstraction, namely: symbolical – detailed quantitative numerical information versus spatial – abstract qualitative information. These two types of numerical representation quite often are presented in the form of numerical tables and charts and diagrams. This leads to the central question of this dissertation:

> "What is the effect of visualised numerical information types on the nature and outcomes of learner's collaborative group decision making and problem solving processes while learning complex domains?"

1.4 Relevance of the research

The combination of changes in working and interacting has raised much research interest, at least, in the area of organisational behaviour, educational psychology, information technology, and applied communication science. Thus the topic of this dissertation touches on many scientific domains. It is expected that the research findings presented in this dissertation, at least, may be used to support or add-value to existing communication science theories by explaining human interaction in technology-based communication process, especially in CMC.

The pragmatic application of the research findings from this dissertation may also contribute to design principles for distance and mobile learning, and tele-working environments. The need to find a fundamental design principle in these two trends are illustrated by one of the surveys in tele-working conducted by British Telecom in 1993 which presents an overview that shows there are 1.27 Million people working by distance in the United Kingdom and about 5.89 Million people in the United States of America. These numbers are respectively 4.6% and 4.8% from the total workforce. It is predicted that this number will grow to 10 and 33 Million people by the year 2010 (Gray, Hodson, & Gordon, 1994). The increasing popularity of tele-working in private and governmental sectors has forced researchers to find solutions to the design of task and interaction support systems to manage dispersed working teams. From other surveys on the popularity of the use of CMC, it was found that Microsoft Network (MSN) supports about 230 millions online users each month and hundreds of thousand on MSN online communities. There are also over 104 million ICQ users and 91500 UseNet groups. Recently IBM hosted an online forum in which 50000 employees worldwide came online to propose and discuss new initiative (Preece, 2001). With the increasing trend of tele-working and the use of CMC tools, the research findings presented in this dissertation are expected to be able to provide more information for the application of CMC in any context of modern working and learning processes.

Other pragmatic applications of the research findings can be to the new trend of computer supported collaborative learning (CSCL) or other trends in mobile learning environments which use only simple communication media to exchange meaning. The findings presented in this dissertation are expected to contribute to methods and techniques to manage and design the visual content of mobile learning environments in order to maximize the quality and effectiveness of collaborative interaction.

The last interesting point of view on KM in general is the existing dilemma for KM as a domain where it creates a gap between “the reality” and “the theory”. Academics deliver advanced and complex research on the benefits of KM in an organisation and practitioners use different KM practices without understanding all their implications in an organisation (Nicolas, 2004). The consequence is that learning KM is most of the time hard to achieve in an organisation due to the size of the gap. There is not much research done as an effort to fill this gap. Researching the link between decision making processes and knowledge management in this dissertation is expected to reduce the gap between the reality and the theory of KM in organisations by providing transparency of communication processes in accomplishing knowledge intensive collaboration and the learning outcomes attained by the communication process.

1.5 Structure of the dissertation

This dissertation covers two main parts. The first part focuses on designing the visual representations of the numerical information that are predicted to be able to support collaborative group decision making and communication, and knowledge intensive task performance – learning KM in a collaborative decision making process. The second part presents the empirical research that investigates the effect of the information visualisation on the decision making process and the consequence of the group decision making process such as satisfaction with the decision making process and learning outcomes.

The purpose of the research in this dissertation is to comprehensively explain the effect of the visual representation of the numerical information on the overall process of group decision making and its consequence - the learning outcomes. Before we can achieve this purpose, scientific investigation must be done conceptually to find the theoretical relationship between the visual representations of the numerical information and the overall group decision making process. Later, the result of the conceptual foundations that link the visual representations of the numerical information to the overall group decision making process will be pragmatically applied to the design process of the visual representation of the numerical information. Figure 1-3, below, shows the overall research approach followed for this dissertation.

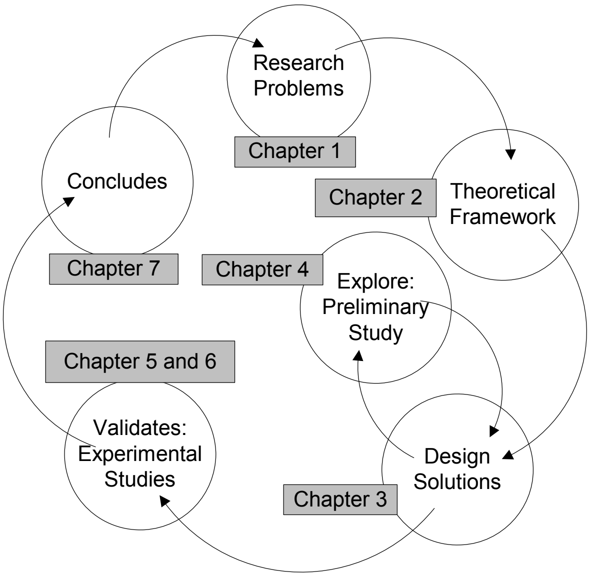


Figure 1-3. Research approach

The overview of this dissertation reflects the research approach in Figure 1-3. After this introductory chapter, the theoretical overview of learning KM, decision making and problem solving as collaborative activities, and the possible contribution of visualisation to support the communication process during problem solving and decision making while learning KM, are described in Chapter 2. The main discussion in this chapter starts with describing the complexity of the task which is due to the fuzziness of KM as an ill-defined domain and the potential of collaboration or team learning. Then the discussion continues to stress the potential impact of text-based CMC in terms of the quality of information sharing activities in the domain under investigation. This chapter finishes by describing possible solutions to reduce the potential impacts of narrowness of a text-based CMC tool with the proper design of visual information such as charts and diagrams.

Chapter 3 presents two applications of the theoretical framework: (1) a learning environment for KM consisting of gaming and simulations; (2) the actual visual designs that were elaborated theoretically in Chapter 2. The application of the KM learning environment is KM Quest^{TM}, an Internet-based collaborative simulation game. This chapter emphasises the importance of visualising the game indicators and how to achieve meaningful visualisations.

Chapter 4 presents the result of a preliminary study that was conducted to evaluate mainly the design solutions. Three issues are addressed: (1) the appreciation of target users of the visual designs; (2) the initial evidence of the role of visualisation for collaborative playing – Learning KM with a gaming simulation; and (3) methodological issues concerning conducting experimental studies to investigate the research question. These findings are useful to provide information on how to improve the design in the real KM Quest system and guidelines to develop the methodological and analytical framework of the experimental studies.

Chapter 5 and 6 presents two experimental studies that aim to test the hypotheses derived from the theoretical overview and visual design principles, concerning the communication process of collaborative group decision making and possible learning outcomes after the group decision making process. Chapter 5 presents the first study that measures the effect of the visualisation of the numerical information on the group decision making process to solve KM problems and investigates the learning outcomes of the group process. Chapter 6 describes a study comparable to the one used in chapter 5 but with modifications based on the results of the study in Chapter 5. Also more refined experimental procedures and methods are applied.

Chapter 7 summarises the research findings from the two studies and discusses the contribution of the findings to the theory and practice of learning KM in collaboration, visual design for narrow bandwidth contexts, and for future research in the same area.

2 Theory: Supporting collaborative communication in a knowledge-intensive activity

The goal of this chapter is to explore theoretically the main research question "What is the effect of visualised numerical information types on the nature and outcomes of learner’s collaborative group decision making and problem solving processes while learning complex domains?"

However, before we can answer this question, attention must be paid to a review of the context of KM which consists of knowledge and skills that will provide a manager with a way of thinking and interacting for dealing with the modern organisational life. KM as a domain and as problem-solving skills to be learned has become a potential solution, but at the same time creates challenges to be understood from the perspective of learning and organisations. The context of learning in this dissertation is limited to learning KM, providing a learning context and approach of the learning organisation. These are believed to link the topics of learning, working, and life-long learning in business management.

In the first part of this chapter, we explain the characteristics of KM as a new domain and its requirements for a learning strategy to master KM as a domain and as a problem-solving skill. In this section, collaboration is seen as a solution for KM that not only will help managers to learn KM conceptually but also help managers to experience the KM activities that require them to manage their own knowledge. Collaboration in this section is seen as providing opportunities for learning and at the same time challenges us to investigate the process of learning as a part of KM activities themselves. Thus, learning KM collaboratively is first approached from learning science theories. Further, the emphasis is on the process of collaboration as a part of KM activities. Later, the gaming and simulation approach is introduced to provide KM with collaborative opportunities in the context of learning organisations.

The second part of this chapter stresses the importance of communication to mediate group decision-making and problem-solving processes during learning KM and experiencing KM activities collaboratively. The consequences of having a narrow-bandwidth communication medium combined with geographic dispersion for the communication processes between managers are discussed. Theories dealing with these kinds of interaction processes in KM and their connection with group communication processes in group decision making and problem-solving are addressed.

The third part of this chapter elaborates the potential of visualisation of numerical information to support the communication of geographically dispersed managers who perform collaborative decision-making and problem-solving while learning KM and experiencing KM activities. The outline of a visualisation strategy that is believed to support the group communication process when learning KM, and which at the same time supports the knowledge intensive KM activities, is presented.

2.1 Knowledge Management (KM): a new domain and experience for managers

According to the organisational learning approach, KM can only succeed when people are no longer seen as containers of knowledge, but as learners. Knowledge is dynamic: people share their knowledge with others, create new knowledge, and gain knowledge from external resources; and in the end the organisation as a whole should profit from these individual learning activities (Dijkstra & Verwijs, 2000). This point of view stresses the importance of KM in a learning organisation and how organisations can benefit from KM to improve their learning capability. But acquisition of KM knowledge, as a domain to be learned, is not as easy as it seems.

As mentioned before, in our perspective the contribution of KM is believed to supply new knowledge about how to manage knowledge to deal with the changing of work characteristics to decision-centred ones. However, acquisition of KM as a new domain constitutes a complex and fuzzy task in the group interaction of managers because the acquisition of the KM knowledge can only be achieved through interactions with others and at the same time involve in a process of solving the main problem in the working environment and learn the consequences. On the other hand, KM is not only difficult to learn, but it also provides other KM problems because managers themselves have to manage their *own* knowledge in order to solve the main problem in decision-centred work. The whole process requires knowledge intensively. Thus, there is a commonality between learning KM as a domain and actually experiencing KM problems. However, parallel at understanding the new concept of managing their knowledge, managers are expected to interact collaboratively when deciding about relevant KM activities. Hence, the way the managers have to communicate and interact to perform KM becomes another central point of the KM problem in this collaborative process. In the situation of geographically dispersed managers, the interaction between the managers may encounter difficulties when performing the knowledge-intensive activities which are required to deal with KM problems. The inter-relation of all these factors will be discussed as the opening issue of this section. An elaboration of what KM is and why KM is not only considered to be an ill-defined domain but also requires knowledge itself to carry it out, will begin this section. Later, the importance of collaboration in performing KM activities is stressed to discover the group dynamics in knowledge-intensive activities.

2.1.1 Knowledge Management: a conceptual process in learning organisations

The premise of KM in the theory of organisation is fairly straightforward - knowledge is considered as a crucial resource in an organisation that has to be managed. Specifically Wiig (1997), in his working definition of KM, said that the goal of KM is: (1) to make the enterprise act as intelligently as possible to secure its viability and overall success and (2) to otherwise realise the best value of its knowledge assets. These two goals basically point to the hope of an intelligent organisation which always benefits from the learning processes as the main processes in the organisation.

As a resource to be managed in an enterprise, knowledge contains very abstract and hard to grasp concepts. There is no general accepted definition of knowledge as a resource in an enterprise. Therefore it is not easy to achieve the goals of KM. Wiig, de Hoog, and van der Spek (1997) suggested that managing knowledge should take into account the unique properties of knowledge, and they come up with a set of methods, tools, and techniques that helps in tackling problems and opportunities that arise from these properties. They describe that knowledge is unique compared to other resources in the following aspects:

- Knowledge is intangible and difficult to measure;
- Knowledge is volatile, it can "disappear" overnight;
- Knowledge is embodied in agents with wills;
- Knowledge is not consumed in a process and sometimes increases through use;
- Knowledge has wide-ranging impacts in organisations ("knowledge is power");
- Knowledge cannot be bought on the market at any time and often has long lead times; and
- Knowledge is "non-rival"; it can be used by different processes at the same time.

These key properties knowledge management should take into account while managing knowledge in organisations

According to them, KM functions through two levels of activities. The function of these two levels is very similar to the standard (cyclic) control theory, as depicted in Figure 2-1.

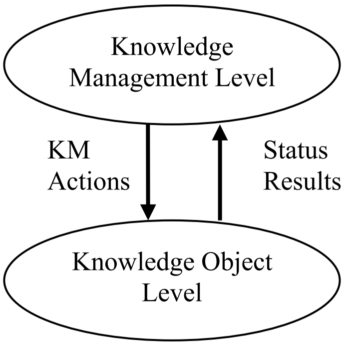


Figure 2-1. Levels in knowledge management.

Figure 2-1 depicts a fundamental knowledge management process that can underlie a generic model of KM activities in an organisation. This generic model ideally will influence the conceptual model of managers in their daily work activities. In adopting this generic model, an understanding of how to benefit from the unique properties of knowledge, a KM model is necessary at the KM level (the top oval in Figure 2-1). This particular KM model is required to meaningfully interpret the object being managed (knowledge) at the knowledge object level (the bottom oval in Figure 2-1). Based on the interaction of these two levels of KM, managers may come up with decisions about a set of KM actions required to handle problems and opportunities at the object level. This cyclic model continues to work as long as the organisation exists. This fundamental process of KM suggests that a KM problem-solving strategy (the content of the top oval in Figure 2-1) will be created, learned, and continuously updated by the managers in an organisation.

If we carefully look at this KM generic model the whole process of KM may be viewed as a knowledge-intensive task itself. Wielinga, Sandberg, and Schreiber (1997) said that knowledge is not only the object of KM, but KM itself requires knowledge of ways to describe knowledge, to develop knowledge, and to maintain knowledge. They said that this recursive nature may cause problems in understanding what actually is being managed. Their statement becomes more relevant if we link it with the complexity of the groups' and individuals' interactions and those between individuals or groups and the physical environment of the organisation (at the knowledge object level in Figure 2-1). In other words, understanding KM is difficult, understanding it together could be even more difficult.

Up to this point, it becomes obvious that KM does not seem to stand independently as "just" a KM generic model only, but also as a complex process that requires managing manager's knowledge collaboratively to deal with the work problem. It becomes crucial if we look at this generic model of KM activities from the learning organisation perspective because the process will be continuously updated through the lessons learned during this cyclic progression to create new KM understanding and skill. Of course, the important question is on how to promote that managers will master KM not only conceptually or mentally but also skilfully in solving problems collaboratively.

When KM has become necessary to learn, in our assumption the learning process to acquire KM is not focused on merely acquiring KM as a mental model only in problem-solving and decision making processes in decision centred work, but also on the experience of being immersed in KM problems itself in order to fully understand KM. It is necessary to carefully review the process of acquiring KM mentally and operationally before we can have clues on how to promote KM and on how to support the process of learning KM collaboratively. We feel that the acquisition of KM as a new domain and a problem-solving skill is a challenge for learning science and KM theories in the learning organisation.

In the next section, the processes of learning KM from these two perspectives are elaborated.

2.1.2 Learning KM: learning an ill-defined domain

It is almost generally accepted that there are no clear conventions on how to use methods, techniques and tools to operate at the KM level. It is acknowledged that the KM level in Figure 2-1 does not contain operational and generic procedures for when and how to solve KM problems, like for example in operational research. One should be aware that the operations at these two levels are very flexible and dynamic regarding problems being faced in daily work. Moreover, the use of the KM generic model in an organisational setting is not straightforward, due to its high abstraction level. It also commonly accepted that the relation between problems and solutions in KM domains is fuzzy and ill-defined. As an illustration, we take questions like: "What is the KM problem?", "How does a manager know that there is a problem in the knowledge object level?", "What does a manager have to do if he/she detects a KM problem?"

These questions make clear that the process of inspection of the knowledge object level requires generic conceptual knowledge or a mental model about what KM itself is, because the nature of the work problem is too multi-faceted, equivocal, and complex (Leemkuil, De Jong, De Hoog, & Christoph, 2003; Leemkuil et al., 2001; Purbojo & De Hoog, 2004). This is probably the foremost problem in performing KM in an organisation. In practice it also turns out to be difficult to address KM problems in a systematic way and therefore people do not choose the right activities and solutions (Christoph, Van der Tang, & De Hoog, 2001). However, this is not too surprising because the definition of knowledge itself is troublesome and not generally accepted - knowledge as the object of management is somehow intangible (see the list on page 13).

We think that there are at least two necessary conditions to be able to master the KM model at the Knowledge Management Level in Figure 2-1: (1) understanding the positive properties of knowledge; and (2) understanding of and capability to perform practical or operational KM procedures (methods, techniques, and tools). Both necessary conditions basically lead to a kind of strategic knowledge in solving KM problems.

The question is how to build up such understanding and knowledge so that the manager can have a better overview of KM problems that occur at the Knowledge Object Level, select appropriate KM actions at the Knowledge Management Level, and learn the consequences of these KM actions to improve strategic insight. Thus, acquisition of KM knowledge is not only seen as the acquisition of a mental KM model only, but also as acquiring strategic KM problem solving skills.

The development of KM problem-solving skills through learning processes is assumed to play a very important role in the work environment. However, the acquisition of problem solving skills requires a carefully shaped learning process. In the learning sciences, problem-solving involves the use and application of skills for finding solutions, making decisions, and thinking inventively (Leshin, Pollock, & Reigeluth, 1992). To solve problems in a domain, Gagne (1980, 1985) and de Jong & Ferguson-Hessler (1986) said that learners must possess and apply three kinds of knowledge: principles, declarative knowledge, and cognitive strategies. The ability to apply principles seems to be the most critical component for problem solving; however it is clear that without declarative knowledge and cognitive strategies, the learner may not able to adequately identify or search the problem space (Smith & Ragan, 1999).

A pragmatic solution that may be offered to develop KM problem-solving skill is by providing managers with a KM problem-solving model at the KM Level that systematically takes the properties of knowledge into account. It is expected that supplying the managers with important knowledge about and principles of KM declaratively, will satisfy the need for a KM model. However, it is likely that providing opportunities to the managers to practice learning on how to use this strategic model in their work situation is necessary in order to master KM problem solving skills. It is expected that understanding the connection of the KM model with the knowledge object level in organisational activities or business processes, as exemplified by the generic KM model in Figure 2-1, can assist managers in developing the required KM problem-solving skills.

Therefore, to achieve the goal of building KM problem-solving skills (1) a well-defined model is needed for the KM level to provide managers with a systematic way of thinking about interacting with the knowledge object level; (2) opportunities for the managers to practice the KM problem-solving model must be created. The former requirement can be fulfilled by picking up one of the available KM models (De Hoog et al., 1999; Wiig et al., 1997). The discussion of choosing or building an appropriate KM model goes beyond the discussion in the theoretical review of this dissertation. However, we are still aware that providing a KM model as a normative model for interaction with work problems is a very important opportunity to build the problem-solving skills and to help structure the mental model of the managers. Thus, we assume that lack of understanding about KM problems can be tackled by providing a KM problem-solving strategic model, no matter what kind of KM model it is.

On the other hand, offering an appropriate KM model might not be enough to cover the complexity of modern job characteristics in terms of involving multiple-agents or managers. Without having the opportunity to apply a model of KM problem-solving to the actual work situation, developing and acquiring KM strategic problem-solving skills will probably not occur. Thus, providing opportunities to practice a KM problem-solving approach needs more attention, because it enables managers to develop strategic KM skills at a higher abstraction or generic level to accomplish knowledge intensive, decision centred and collaborative work.

Creating opportunities to let the managers apply a KM problem-solving model in collaborative settings is part of the focus of the research reported in this dissertation. It is not only important to provide meaningful opportunities for the managers to learn KM, but also to have opportunities to build strategic problem-solving skills by experiencing the consequences of applying the KM model in collaborative practice as well. This latter point requires the managers to interact with each other in a knowledge intensive manner – which is typical for one of the KM problems that are commonly found in an organisation. In the next subsection, theoretical insights that might help us to clarify this collaborative process, are discussed.

2.1.3 Learning KM in collaboration: experiencing knowledge-intensive tasks

The arguments in favour of having a KM model in learning KM, put forward in the previous subsection, could also be deduced as a pragmatic solution to the learning process of acquiring KM as a new domain. Although there is nothing wrong with this deduction, we feel that providing collaborative opportunities in learning KM is needed much more to develop KM problem-solving skills in an organisation. It is assumed that the collaborative situation, when learning to understand the function of the KM and knowledge object level in the basic knowledge management process and applying KM problem solving skills not only will contribute to individual skills in term of personal mastery of KM, but it is even more important to expand the capability of managers as the fundamental unit of organisation. This sets teamwork and collaboration between managers in the organisation as the most important factor in a learning organisation. This can be achieved because the diversity of the knowledge processes in the collaborative interaction provides opportunities to the managers to take advantage of the diversity of knowledge and to (re-)construct their knowledge to gain a higher competence in solving KM problems.

From the perspective of KM in organisational learning, team learning has received more priority and attention than individual learning. Van Heijst, van der Spek, and Kruizinga (1997) stated that in order to be able to promote learning in an organisation, individual learning must be accompanied with the bottom-up learning process through interaction and communication where individual learning is shared with other managers in a team. Wenzler and Chartier (1999) who quoted Senge (1990) also say that individual learning, at some level, is irrelevant for organisational learning. According to Senge, team learning is vital because teams are the fundamental learning unit in modern organisations and it contributes to the skills of groups of people to (1) look for the larger picture that lies beyond the individual perspective – having only specific processes, tasks, responsibilities, and activities is not enough; (2) build an understanding of possible futures that an organisation might encounter; (3) build a situation of learning together; (4) developing one's capability and confidence to make judgements and act in ever-changing circumstances – knowledge of facts alone is far from enough to allow an organisation to embrace and being committed to change.

Van Heijst, van der Spek, and Kruizinga (1997), also said that team learning through communication is more efficient, because the communication process forces the lessons learned to be articulated, which improves its understanding. Almost in the same way, Schrage (1990) said that collaboration is a purposive relationship to solve problems, create or discover something that may add to the richness of team learning to create meaningful learning opportunities. He says that collaboration is a far richer process than teamwork's handing off on an idea or blocking and tackling for a new-product rollout or attempting a slam dunk marketing manoeuvre. It is creation of values in management.

From the perspective of learning science, collaborative group-based learning is believed to be relevant to create learning opportunities in work settings with the synergy of building competence levels and skills in handling daily work. This concept fits perfectly with the idea of a learning organisation and is suitable to support learning of strategic knowledge and enhanced critical thinking in KM domains.

Johnson and Johnson (1990) expressed the need to benefit from group-based collaborative learning by saying that education and business have come to recognise the significant learning gains and increased creativity which develop from learning and working collaboratively in groups or teams. Kunkel and Shafer (1997) said that business recommends that curriculum and teaching methods be modified to better develop cognitive, communication, and interpersonal skills through the use of student groups in the learning process. Nelson (1999) says that group problem solving becomes one of the most common and natural situations in which we accomplish our work. She mentioned that collaborative problem solving may add to the value of learning by means of:

- Honouring the importance of authenticity, ownership, and relevance of the learning experience for students in relation to the content to be learned and the process by which it is learned;
- Allowing students to learn by doing as active participants in their own learning-process;
- Fostering the development of critical thinking and problem-solving skills;
- Encouraging the exploration and analysis of content from multiple perspectives;
- Acknowledging the importance of rich social contexts for learning;
- Cultivating supportive, respectful relationship among learners, as well as between learners and the instructor;
- Developing a desire for life-long learning and the skills to sustain it.

All these points add to the value of learning processes in general. However in our view, the added-value of collaboration is not only to improve the acquisition of KM as a mental model dealing with daily tasks, but also creates opportunities for managers being involved in collaborative knowledge-intensive tasks collaborative as they encounter in daily work. Thus, learning KM extended with collaboration is seen as providing managers with an immersion in KM problems – a situated learning condition. Learning KM may serve a reflective learning atmosphere by applying a KM model and by being involved in knowledge intensive activities as required in decision-centred work. It is believed that collaboration creates a rich and meaningful opportunity to managers to develop their understanding of KM conceptual knowledge and KM as problem-solving skills. Adding a collaborative element to the setting of learning KM will enhance the value of KM as not only the content of what is learned but also by creating the actual context where the content of learning will be experienced as a problem-solving strategy in the social setting of an organisation. Referring to the development of a strategy, Nicolas (2004) stated that strategy development has been described as a social learning process, where relatively autonomous actions are nurtured an promoted by middle managers until they eventually become a part of or actually shape the organisation's official strategy. He stressed the importance of social learning processes in developing strategy in management. This opportunity is very compelling, because according to learning science theory, collaborative learning is a promising approach to acquire excellent learning outcomes when dealing with strategic knowledge and cognitive strategies to solve problems. Learning in teams was a mixture of learning two kinds of expertise: learning about the content and learning about the process, or "learning what" and "learning how" (Huysman et al., 2003). In the same way, in the perspective of KM and organisational learning, collaboration is seen to provide managers with opportunities to learn a generic KM problem-solving strategy through knowledge-intensive activities. The knowledge-intensive activities will let managers learn from each other and experience the social interaction activities as a part of the problems that they might encounter in the daily tasks making up decision-centred work. For instance, being a team of knowledge managers will add to the value of learning KM and at least increases the awareness of what is the importance of KM in decision-centred work.

All of the above suggests that collaboration is very important and must be further developed in KM and learning science theory within the framework of learning as the central process of modern organisations. For instance, the decisions about using knowledge as a resource in an organisation will depend on how a team reasons about these decisions following a KM conceptual model collaboratively. The success of selecting KM interventions is highly dependent on the interaction and communication in the collaboration process. Junnarkar (1997) said that KM in its most simplistic form is operationalised as (1) connecting people with people: leveraging the collective intellect of many people. Although we can connect all managers within an organisation by leveraging ICT, to leverage each other's intellect is much more difficult; and (2) connecting people with information: enabling sense making of information as not only pieces of information, but to make something out of the information, understand it, make connections with disparate pieces of information, identify trends, recognise patterns, and ultimately create insight. From our perspective, Junnarkar also stresses the importance of collaboration in KM explicitly. Therefore, we believe that letting managers learn KM collaboratively is the appropriate solution to master KM as a mental model and, possibly the most important one, as for developing strategic problem-solving skills.

Summarising this and the previous subsection, the need to learn KM in an enterprise is strongly present to support managers to deal with the complexity of decision-centred work. To fulfil this need, KM may supply a model of KM problem-solving that takes into account the positive properties of knowledge. From the educational science perspective, we must let managers apply this model in their decisions that are related with KM and learn the consequences. However, the work situation also requires that managers interact with each other in complex ways and possess the knowledge to deal with the interaction to reach a decision about KM actions collaboratively. This requires KM to act not only as conceptual knowledge but more as an activity that itself is knowledge intensive and requires collaboration.

The consequences of this, in our assumption, are best approached by not only providing KM as a mental model of a problem-solving strategy, but also by creating opportunities to apply this mental model to a context where KM activities can be found. Thus, in this sense, expanding collaborative learning in learning KM as a domain does not only create meaningful learning opportunities to master KM as a concept, but also KM as contributing generic problem-solving skills. Collaboration provides rich learning opportunities, but also enables managers to perceive lessons learned from experiencing KM activities while learning KM collaboratively.

Thus, the challenge is to provide the opportunities of learning KM in collaboration as a representation of organisational learning. In the next sections, we outline how we can meet this challenge.

2.1.4 A challenge: creating opportunities for learning KM collaboratively in the context of learning organisations

In the context of organisational learning Watkins and Marsick (1993) stated the following characteristics of learning:

- Technology has been a key player in satisfying learning needs; it allows for flexible, tailored, just-in-time training via the computer, video, and telecommunication in a variety formats, from fairly conventional video packages to interactive, live distance learning;
- Learning is carried out through discussion between the employee and others with whom the employee interacts, including the trainer, by considering organisations and people within them, as self-organising, self-monitoring, self-correcting entities that function somewhat like the brain;
- People must learn continuously from their experience as they face new challenges for which there are no right answers.

Additionally, according to Kriz (2003) the goals of learning processes in organisations should be supported by the realisation of internal and personal development measures and continuing education. They should not only procure new knowledge and competencies, and acting strategies in the context of existing norms (single-loop learning) but also foster a deeper understanding of any changed convictions, judgements, and rules, as in double-loop learning systems according to Argyris and Schön (1996).

These points lead to a combination of formal and informal learning approaches: formal methods for basic preparations, abstract and complex thinking, and routine procedures, and informal methods for on-site decision making, tailored solutions in a specific context, and exceptions to the rule. This might be achieved by three strategies: (1) linking formal and informal learning through better planning; (2) helping employees learning how to learn and think in more complex ways; and (3) supporting performance through just-in-time training and learning. Some scholars claimed that those strategies can be achieved by (computerised) simulation and gaming approaches (see Carson, 1969; Corbeil, 1999; De Hoog et al., 1999; Druckman, 1995; Gredler, 1996; Isaacs & Senge, 1992; Klabbers, 1999; Kriz, 2003; Leemkuil et al., 2003).

Through a simulation and gaming environment, managers can interact freely without worrying to make mistakes that endanger the real working situation. A game is a perfect manifestation of safe curiosity (Corbeil, 1999). Simulation and gaming allow managers to experiment with new policies that would be difficult or impossible to attempt in practice, in order to develop new insights into the nature of the system within which one is operating, and new skills for managing that system (Isaacs & Senge, 1992). This approach has also been considered as an interesting learning opportunity due to its ability to mimic processes, networks, and structures of specific existing systems, for instance in business process and organisation. Klabbers (1999) said that “Games are social systems. They include actors, rules and resources, which are the basic building blocks of a social system. They are also models of existing…social systems”.

Similarly Kriz (2003) said that simulation and gaming require players to act within expected roles in the process of learning. He also said that the design of simulation and gaming offers a perfect learning environment for the training of social skills, the (re)construction and sustainable development of social systems, and dealing with the complexity of modern corporate life. This will increase the willingness of the employees to transfer their experience and to make use of learning opportunities through collaborative simulation games. He mentioned also that learning is considered to be a self-organising process in which person-internal factors alternate with person-external factors, so-called situational conditions. The concept of situation means both material and social environmental variables. The interaction between people and the cultural frame in which a person’s thoughts and actions are embedded plays an important role.

Wenzler and Chartier (1999) suggest that the process of developing and implementing games and simulations in organisations is one of the most effective approaches in enabling organisational learning. Games and simulations help organisations to develop symbolic thinking and gestalt understanding; help them create memories of the future; enable shared experiences and building of shared intelligence; and possibly most important, they develop their member’s motivation and confidence to act.

Epistemologically, using games as learning tools is also not a whimsical decision but rather a deliberate one to regulate the basic mechanism of learning (Corbeil, 1999). According to Garris, Ahlers, and Driskell (2002) the use of games in professional training is increasing due to (1) the major shift in the field of learning from a traditional didactic model of instruction to a learner-centred model that emphasise a more active learner role; (2) to some extent, some empirical evidence exists that games can be effective tools for enhancing learning and understanding a complex subject matter, recent research has begun to establish a link between instructional strategies, motivational processes, and learning outcomes; (3) the intensity of involvement and engagement that (computer) games can invoke can be a compelling and rewarding experience.

Therefore it is not surprising to see that in research and development of computer-based environments, the application of simulations and games has attracted much attention. Games and simulations promise to open a window on individual and team learning patterns that can help in diagnosing managerial learning disabilities and designing improved learning process (Isaacs & Senge, 1992). We think that it is reasonable to say that simulation and gaming promise to create opportunities to share visions, exchanging of individual mental models in groups, developing skills for teamwork and team learning, acquiring personal mastery, and thinking systematically (Senge, 1990). However, despite the promising benefits of gaming and simulation, research into using games to promote learning is still infrequent and inconsistent (Druckman, 1995; Pierfy, 1977). Besides, in the field of educational science, games (including computer games) have not been widely accepted as learning tools (Corbeil, 1999).

In this dissertation, we are aware that the position of gaming and simulation is providing an environment where we can further investigate the process of collaboration in organisational learning and KM domains. We believe that technology adds to the value of collective interactions in an organisation and in computer-based learning by simulation and gaming. It is believed to enhance organisational learning by making explicit the assumptions and logical inconsistencies in the operating policies of an organisation, fostering shared understanding of complex organisational processes and systems, and by exposing the gaps between ways managers believe they behave and the ways they actually behave (Isaacs & Senge, 1992). The comparison of the effectiveness of gaming and simulation with other learning solutions to teach KM in a collaborative setting is not the research topic of this dissertation. Gaming and simulation are taken as the given environment to investigate effects of visualisation of information. The design and implementation process of simulation and gaming approaches to support learning KM in collaboration will be further elaborated in the next chapter.

2.1.5 Communication in collaboration: a problem and an opportunity

Although collaboration is seen as a very promising way to develop KM problem solving knowledge and skills, collaboration itself is seen as a complex process in learning and KM theories that requires a careful approach. In this section, we stress the importance of the communication process in collaboration.

Sveiby (2002) stated that collaboration is one of the major factors influencing effective knowledge work. The effectiveness of knowledge work has to do with how the creation of new knowledge and transfer of existing knowledge is organised (Nonaka & Takeuchi, 1995). Sveiby also said that even a careful design of information sharing systems does not promote willingness of people to share their knowledge. The trouble is that knowledge is not a discrete object and that the most valuable knowledge is embedded in people. Argote and Ingram (2000) argued that companies can utilise this feature strategically by embedding knowledge in interactions involving people.

From the perspective of a collaborative learning process, Nelson (1999) also suggests that one of the key issues in collaborative learning is the interaction between learners. Learners need to be able to (1) make meaning of what they are learning and how to understand how it fits into their learning goals and project work; (2) develop the skill to correctly interpret and evaluate the various types and sources of information they gather. These two requirements are the key points in the process of shared knowledge creation in general. Thus, communication in terms of collaborative interactions should attempt to meet these two requirements.

Logically, what is suggested in the previous statements is that collaboration as a process in learning and carrying out job tasks, is equivalent to a communication process to make meaning of the problem being solved and to create the skills to correctly interpret and evaluate the various types of information. Thus, the process of communication, as an element of the interaction between people in collaborative learning and working, is a very important condition in the learning process and in

KM activities. Through collaborative communication processes managers obtain a better picture in understanding tasks in decision-centred work and they can benefit from this process to develop their learning process to handle problems in the future.

However, in daily work, the communication process in collaboration is complex. Most of the time the problems that managers encounter are difficulties in communication while carrying out knowledge-intensive activities, such as infrequent opportunities to meet face-to-face during complex decision-making or problem-solving processes. In this case, the mediated communication adds to the problem of learning KM in collaboration which itself leads to multifaceted tasks. Improving the communication becomes one of the keys to solve the KM problems. In our case, the most important thing is to provide the managers with opportunities to experience KM problems and trying to solve them collaboratively. We expect they can learn the consequences of their group problem-solving and decision making communication process collaboratively. This has led us to the conclusion that the process of experiencing collaborative problem solving in the KM domain gives the best experience in an organisational learning process. The process of dealing with KM problems collaboratively is a difficult task, due to the complexity of the communication process, but at the same time it creates a valuable opportunity.

Given communication as the main backbone of collaborative group processes, it needs special attention to reduce its potential negative effects. The main idea of this dissertation is in line with this premise. Providing support for the collaboration process must be realised by reducing the complexity of communication. Before we can have ideas about how to support this communication process, an overview of communication processes in group decision making and the effect of mediated communication is needed, which will be discussed in the next section.

2.2 Communication as the backbone of group problem-solving and decision-making

As explained in the first chapter, one of the consequences of the move toward decision-centred jobs is that communication between managers is mediated technologically due to their increasing geographical dispersion. There will be less and less need for managers to have face-to-face meetings because of the cost effectiveness of mediated communication. In this sense, technologically mediated communication in organisations has become the main backbone of daily organisational work to manage a workforce across geographical boundaries. Looking at communication as the fundamental factor to achieve a meaningful interaction in collaborative processes, the use of technologically mediated communication in geographical dispersed teams may influence the way team members interact. This leads to the assumption that the accomplishment of tasks will be highly dependent on the communication process that accompanies task performance.

In the previous section, it was stated that the nature of communication in collaboration will be the main theme in this dissertation. Some theories hypothesise that in conditions where the communication modalities are not supportive to the task, this can seriously impede task performance and consequently the quality of the decisions. However, we know that the medium of communication is not the only factor in group decision making and problem solving.

In this section, the elements of the communication process such as modalities, models of decision making, tasks characteristics, and the importance of cognition in communication are reviewed and further elaborated to present predictions about potential threats to the effectiveness of collaborative communication in problem solving and decision making.

2.2.1 Communication in group decision-making and problem-solving

To begin with, for group decision-making and problem-solving a task should exist to be carried out by groups. A task is set of problems and issues confronting a group that aims to seek a solution acceptable to its members (Huang, 2003). By definition, decision making and problem solving are two sides of the same coin. Mostly decision making processes involve problem solving, but also the other way round. Johnson and Johnson (2000) say “making decisions is a step further from the problem solving process of goal directed groups-but it is crucial one”. Making decisions and solving problems collaboratively are two interchangeable concepts. In this dissertation decision making is a decision process with group communication to solve problems collaboratively.

In the daily life of business and management, managers might face problems such as deciding to establish a new direction for their company (Kepner & Tregoe, 1981). This process requires an effort of not only to communicate in a coordinated way among staff members, but also to perceive the main problems itself. Similar to our perspective on KM, decision making to solve KM problems is considered as a knowledge intensive activity which also requires communication to coordinate team members. Decision making is an integral part of all managerial functions performed in an organisation. It is a knowledge intensive process that demands good management of knowledge to generate a desired process outcome (Joshi, 2001). We feel that collaborative managerial decision making goes beyond the context of just solving the problem, because it also results in learning effects as the consequence of experiencing the managerial decisions collaboratively. Hence, a tight connection is created between the process of making decisions and learning the consequences of the decisions with the objective of solving the problem.

The communication in group decision making can be explained by a phase model of group decision making as shown Figure 2-2 (Guirdham, 1996). Groups move from one phase to another, when the sub-tasks and sub-goals in the current phase have been completed. Each phase contains communication tasks that have to be achieved as a necessary condition for a successful group decision making process.

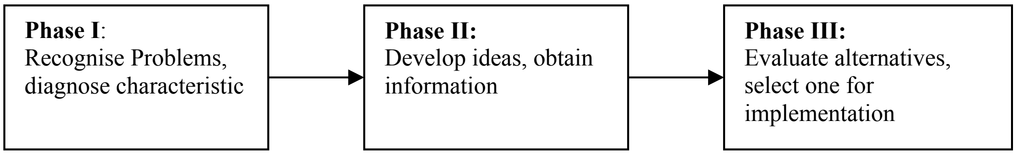


Figure 2-2. Phases in group decision making (Guirdham, 1996).

This is a general model of group decision making, the practice of making decision to solve problems does not always follow the orderly step-by-step sequence as depicted in Figure 2-2. Most of the time, the process of making decision is much less tidy: back-tracking and leapfrogging are usual, while some members will overlook one or more of the stages altogether. Interruptions, delays, and repeating arguments also might show up in complex decision-making processes. Thus, it is argued that strategic decision making is not a steady progression from one activity to the next one, but it a dynamic process with periods of acceleration and delay. There are two common communication topics in this process: (1) *Comprehension cycles* in which the members try gradually to attain a better grasp of a complicated problem by posing questions. (2) *Failure cycles* in which they must return to previous phases if, for instance, conflict stands in the way of an acceptable solution.

To have a better overview of the communication in group decision making, the phase model of group decision making in Figure 2-2 is mapped to a simplified version of the model of problem-solving from Simon (1960) (in Marakas, 1999). The extension of Figure 2-2 is described by the model in Figure 2-3. Figure 2-3 shows that each phase of decision making or problem solving has a new label: intelligence, design, and choice. They are basically the same as shown in Figure 2-2. For example, in the intelligence phase or phase I, participants will try to recognise and diagnose characteristics of the main problem.

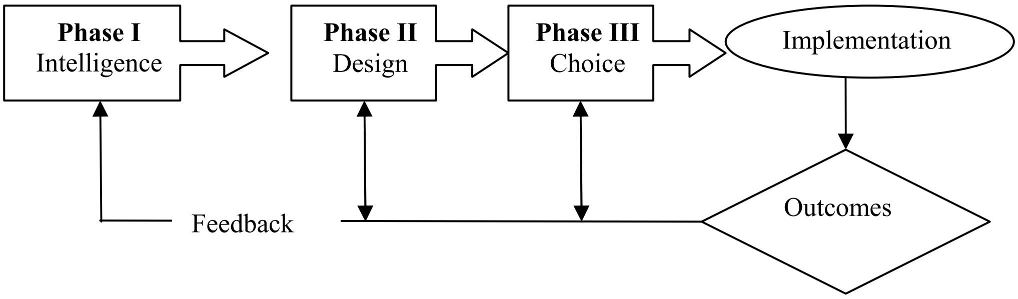


Figure 2-3. Simplification of Simon's problem solving model (adapted from Marakas, 1999).

In decision-centred work, the task to solve KM related problems is believed to resemble the problem-solving model presented in Figure 2-3. For example: a decision must be taken to solve the problem of disappointing of marketing results in a multi-national company. This will require many managers to make a decision about the strategy to tackle this problem. The communication among members to approach this problem will likely follow the sequence of the model, probably with some iterations. We also think that the collaborative communication process in making KM decisions and solving KM problem and learn their consequences will follow the above model. We adopt this model as the model of collaborative communication processes in group decision making to solve KM problems and also to learn KM in collaboration.

Figure 2-3 implies that communication processes in collaboration will occur in all the phases in this problem-solving model. Generally, the nature of the communication process will co-determine the effectiveness of the overall decision making process and outcomes. However, in this dissertation, we do not want to argue whether the decision outcomes are correct or appropriate to the problem, as the process of making collaborative decisions itself does not guarantee the appropriateness and accuracy of the outcomes. Thus the focus is on process characteristics, not whether the decision is “right”. For this, we borrow the following category of assessing overall decision making processes from Scott (1999):

- Task/decision performance (quantity and quality of output, as well as consensus about and commitment to a task/ decision);
- Efficiency (minimal expenditure of resources, especially in terms of time, needed to complete tasks);
- Member satisfaction (with process and outcome, as well as with the group and its members);
- Communication (participation, influence, information exchange, and specific message type).

Based on the above categories, the effectiveness of the overall decision making processes can be evaluated.

In the next section, collaboration as the basic motive of group processes in decision making and problem solving is discussed to understand its nature and requirements.

2.2.2 Collaborative communication in group decision making

Generally, collaboration is defined as an effort to collaborate, especially in an intellectual endeavour. In a dialog or conversation to collaborate, the course of communication follows innate communication principles of cooperation. Grice (1975) states that each participant expects conversational contributions, as they are required in cooperation, to follow the accepted purpose or direction of the talk. He mentioned that there are several general assumptions in the discourse in cooperative conversations:

- Our talk does not normally consist of a succession of disconnected remarks, and would not be rational if they did;
- They are characteristically, to some degree at least, cooperative efforts; and each participant recognises in them, to some extent, a common purpose or set of purposes, or at least a mutually accepted direction;
- This purpose of direction may be fixed from the start, or it may evolve during the exchange; it might be definite or indefinite as to leave very considerable latitude to the participants (as in a casual conversation);
- But at each stage, some possible conversation moves would be excluded as conversationally unsuitable.

- We might then formulate a rough general principle which participants will be expected to observe, namely make your conversational contribution such as is required, at the state at which it occurs, by the accepted purpose or direction or the talk in which you are engaged. Grice's maxims of cooperation in conversation are:
  - Maxim of quantity: make your contribution as informative as required, but do not make your contribution more informative than is required.
  - Maxim of quality / be truthful: do not say what you believe to be false. Do not say that for which you lack adequate evidence.
  - Maxim of Relation / be relevant: make your contribution relevant to the aims of the ongoing conversation.
  - Maxim of manner: avoid obscurity of expression; avoid ambiguity. Be brief. Be orderly.

Generally, Grice expressed that in a communication dialog or conversation there are always general principles about cooperation to reach mutual communication goals. Communication processes in group decision making hypothetically follow the above principles if the situation allows participants to do so.

In our case, this suggests that to achieve cooperative conversation in solving KM problems, there must be a constructive and cooperative effort to ground the understanding of the problem being solved. Grounding the information about the problem being solved has become the necessary condition for the course of conversations in group decision making and problem solving in general. From an educational science perspective, Nelson (1999) mentioned that meaningful collaboration can be achieved in two ways: (1) creating a supportive social context in which learners can freely interact with one another as they engage in their problem-solving groups; and (2) creating abundant opportunities to organise, analyse, and synthesise their findings as they begin to integrate them into their solutions.

What Nelson is trying to point out is, that through a common understanding of the main tasks (problems being solved), collaboration will occur in the course of dialogs associated with communication efforts. Therefore, the communication process in collaborative interaction must intend to reach a common understanding of the problem being solved. From the perspective of communication interaction in collaborative work, Fussell, Kraut, and Siegel (2000) have found that successfully grounding the utterances to achieve a shared understanding, requires communicators to perform a number of conversation subtasks: (a) they must identify what their partners are attending to, in order to determine whether an object is part of their joint focus of attention; (b) they must monitor their partner's level of comprehension, so that they may expand or clarify their utterances if necessary, and (c) they must strive for efficiency in message formulation by constructing their utterance in accordance with Grice's principles of cooperation.

An interesting question that can be posed at this point is how these collaborative communication requirements can be achieved by a combination of communicators, tasks, and media to produce good teamwork in knowledge intensive tasks, such as solving KM problems. Good teamwork means that everyone shares ideas and can draw upon the resources of the entire team to solve problems (Gray et al., 1994).

A unique feature of collaboration in decision-centred work is to encourage good teamwork that does not only have to solve problems, but also to stimulate team learning to expand the capability to solve the problem as an organisation. Thus, the value of the collaboration in group decision making is a crucial point for producing a better solution for the problem, but at the same time must promote learning outcomes afterwards. However, the process to achieve collaboration is not only complex, but it also requires an effort to avoid a faulty communication processes that leads to inappropriate decision processes and causes wrong lessons-learned at the end.

Sources of errors in communication can be (Guirdham, 1996): (1) environmental noise; (2) medium cannot filter the noise; (3) communicators select, distort, decode inaccurately, categorise indiscriminately and wrongly interpret the messages – information overload; (4) communications are more than words - all behaviour conveys some messages. These four potential factors stress the importance of the communication medium to contribute to a better information exchange, especially in group decision making and problem solving.

In the next section the bandwidth of the communication medium is elaborated to investigate possible medium related communication problems.

2.2.3 Communication bandwidth and accomplishment of the main task: media richness vs. task characteristics

The operational model of group decision making (in Figure 2-3) suggests that communication is a vehicle to exchange information between members of a group while carrying out the group decision making collaboratively. This assumption leads to the prediction that the quality of decision outcomes at the end of a decision making process is highly dependent on the quality of the communication process for exchanging the relevant information that potentially contributes to solving the problem.

The communication medium plays an important role to create a meaningful information exchange among members in a team. The media richness theory (Daft et al., 1987; Daft & Wiginton, 1979; Dennis & Kinney, 1998) relates task uncertainty and equivocality to the suitability of medium types for effective communication. Task uncertainty is characterised by a lack of sufficient information and could be alleviated by obtaining and sharing the needed information. Equivocal tasks are those which have multiple and possibly conflicting interpretations of the available information, presenting a challenge for participants to arrive at a shared meaning of information. This theory postulates that richer media (such as face-to-face) enables users to communicate more quickly and to better understand ambiguous or equivocal messages in a given time interval. Therefore, richer media leads to better group performance to accomplish equivocal tasks. This theory also suggests that leaner media tends to support the execution of low equivocal tasks better than the richer media that may provide communicators with superfluous information.

Other studies on communication processes under restricted modality, for instance the ones conducted by Rutter and Robinson (1981) and Williams (1977), confirm the importance of the communication channel to mediate information that is not only required to accomplish the main task, but also to mediate information that is important to build interpersonal relationship to perform the main task. They concluded that relatively cueless conditions (for instance audio only condition) are classified as narrow-bandwidth media, and they are relatively efficient forms to transmit pure task information only. The more cueless an interaction is, the less distraction from other cues (for example, interpersonal cues) that are not task-relevant will occur. But on the other hand, the channel must not be too narrow so that necessary interpersonal cues, required to perform the task, will not be eliminated. An excessively narrow-bandwidth channel may cause a failure to perform the main task, because information that is directly related to the main task and interpersonal relations are not transferred through the medium. This statement confirms the media richness theory, that suggests that the more complex or difficult tasks are, the more they need broader-band communication media. The consequence of having communication through an extremely narrow bandwidth channel can be a less well-articulated structure of interpersonal relations among members of the team. Not only does the group fail to develop meaningful communication interaction that reflects role differentiation, leadership, and so on, but members are less happy and less attracted to the overall group processes and team members. Palmer and Speier (1998) also concluded that team effectiveness declines with team virtualness due to the lack of the interactions over rich media and, in particular, face-to-face encounters.

What is stressed in this section is that the broadness of communication channels plays a key role for the quality of the accomplishment of tasks, due to its capability to transmit task-related information as well as transmitting interpersonal cues. Both types of information, task and social information, are highly related to the accomplishment of tasks. But the proportion of task and social information needed to accomplish a task is expected to be dependent on the characteristics of the task itself.

At this point, it is concluded that a good fit between the characteristics of a communication medium and the main tasks, can increase the probability of a successful task accomplishment. But looking at the requirements of the group problem solving and decision making process in solving KM problems in decision centred work that consists of knowledge-intensive tasks, the media richness theory may not be sufficient to explain and find the potential supportive elements for the mediated communication process. It is hypothesised that relying on media richness theory only to understand the communication process, especially the mediated one, will fail to give an overall overview on how to understand and possibly improve mediated communication. This forces us to look at another perspective on communication in organisations as a process of information exchange and processing, as the basic collective process of communication. Therefore, in the next section, the information exchange theory that considers information processing is discussed.

2.2.4 Cognitive functioning in information exchange theory: an overlooked factor in communication

Summarising to the role of communication in group decision making, we can draw the conclusion that the goals of the communication are: (a) distributing information; (b) conditioning information processing, and (c) analysing and evaluating actions collaboratively (Hirokawa & Poole, 1996). This introduces the assumption that the goal of communication is basically to distribute information to the members of the team and at the same time supply crucial information to the individual cognitive process to construct common a ground for the problem being solved and evaluating the action of making a decision. This may also indicate that communication, by nature, is the process to connect individual cognition and information from/to the outside world (see Figure 2-4).

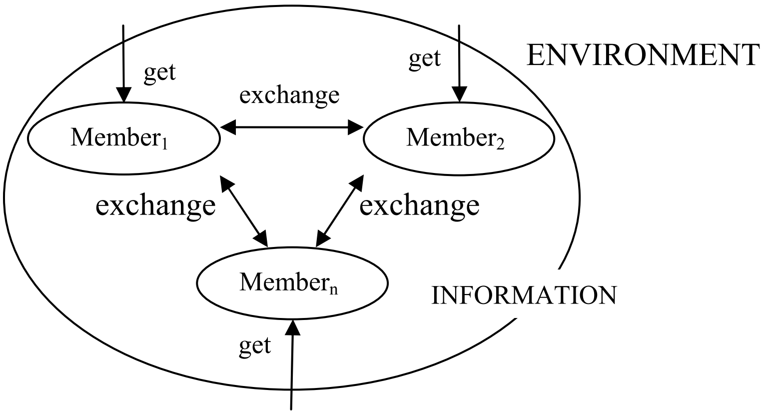


Figure 2-4. Information space.

Figure 2-4 depicts this information exchange as having two aspects: information from the (external) environment and information as a product of interaction. These two repeating steps of information exchange point out the main function of information processing in human cognitive processes. The task of assessing the knowledge held in common by members of a community, such as managers in an organisation, is a complex one, and involves a variety of inferential and judgmental processes. Individuals may utilise a variety of knowledge structures, such as schemata, stereotypes, and inference heuristics to estimate what others know (Boland, Maheshwarei, Te'eni, Schwartz, & Tenkasi, 1992). Figure 2-4 suggests that cognitive processes inside every member of a team plays an important role in independently maintaining the transaction between acquiring external information and information exchange by means of communication.

Thus, the function of cognition and mental abilities to process information and to perceive the meaning of information is also influenced by (1) the capability of a communication process in a certain medium to convey the relevant information from the environment and (2) its own capability to understand the information being exchanged. However, we can not fully rely on the cognition process to align the external information and the information as the product of communication, as only a finite amount of information processing can be effectively performed by human cognition during a given period of time (Kramer & Spinks, 1991). Although there is no universally agreed upon definition of individual cognitive processing capacity, we are aware that the most common risks of cognitive limitations in decision making and problem solving are biases and misconceptions about the problem being solved. Tversky and Kahneman (1974) stated that most people have a tendency to rely on heuristic principles, or rules of thumb, to simplify the process of problem solving and making decisions. Below three of the most common heuristics are enumerated:

1. Recent and past occurrences (availability) – we tend to assume that what is available in memory will be more likely to occur again, and soon, in the future
2. Representativeness – we tend to asses the likelihood of an occurrence by trying to match it with a pre-existing category
3. Anchoring and adjustment – we do not make choice out of thin air; usually we start with some initial value or basic assumption (different values, often unchallenged, lead to different choices).

Each of these three bias heuristics influence human thinking processes. For instance, these biases include insensitivity to prior probabilities, misconceptions about chance, insufficient judgment, and overconfidence because there is a tendency that people ignore base rates and remember singular instances and tend to overestimate the frequency of rare events (Lichtenstein, Slovic, Fischhoff, Layman, & Combs, 1978).

However, the risk of bias in human thinking processes is not always deeply embedded in cognition. Dennis and Kinney (1998) stated that individuals differ in their ability to process images, verbal, and written information so that performance for some individual may depend heavily on the format of the information as communicated through the medium. Gigerenzer (2000) also states that cognitive strategy in human reasoning tends to be influenced by the information format. This suggests that the risk of bias in human thinking process might be reduced by a proper representation of the information.

Taking the above line of arguments, the exchange process of the information from the environment and the distribution of information to others, may be supported by means of increasing the quality of external information representations, which are friendly or can lubricate the cognitive processing to avoid biases and misconceptions through communication processes. This point is implicitly mentioned by Nelson (1999) who stated that support is required for members of a collaborative group to correctly interpret and evaluate the various types and sources of information they gather. When the quality of the information representation is increased, it is expected that limitations of the cognitive processes can be overcome and also reduce the risk to produce bias in making decisions. It is expected that a better collaborative communication process will also contribute to reducing the limitations of individual communication processes. For instance, through questioning, probing, and reflective elements, problem solving is much more likely to avoid misconceptions and other biases (Marquardt, 1999). The process of communication and cognition is expected to act as an error correction mechanism in collaborative communication during task performance. Hirokawa and Poole (1996) state that indicators of a successful distribution of information are precise statements, internal consistent statements, relevant statement, positive reinforcement statements, and statements emphasising cooperation and teamwork. As a consequence, this process will lead to better decision processes and solutions to the main problem. At the opposite, indicators of low quality communication are numerous highly abstract statements, internally inconsistent statements, irrelevant statements, negative reinforcing statements, facetious statements, and statements reflecting a desire to withdraw from the group. In our view, low quality communication therefore, might produce dissatisfaction with the overall decision making process for each member of the team.

Summarising this section, the quality of communication to carry out collaborative group decision making is crucial to the overall group process. In some theories, the limitations of the communication channel strongly determine the effectiveness of the group to accomplish the task. The richness of the medium may add to the value of the communication process, but it can also lead to errors or ineffective communication processes. It is assumed that there is always a trade off between bandwidth of the channel, characteristics of the task, and effectiveness of decision outcomes. However, according to our point of view, bandwidth limitation is relative to the task because the function of cognition to process external information should not be omitted if one fully wants to understand the effectiveness of group decision making in solving problems.

One factor that is often overlooked in understanding communication as a way of exchanging information, is the role of cognition to solve the problem collectively. The function of communication does also influence collective thinking of a group due to its ability to exchange members' cognitive understanding. Communication is used to convey the problem representation to individual cognition. However, theoretically human cognition has also limitations in understanding the information. As a result of the limitations, the perception of existing problem presentations can be limited as well. It is the role of communication to balance the individual understanding of the problem between team members and also mediate the perceived external information. Thus, supporting the cognitive process, by means of taking care of the quality of external information representation, is expected to improve the cognitive processes and communication processes at the same time. Hence, it produces decision processes and outcomes that can be judged on criteria such as mentioned by Scott (1999).

In the following section, we will use this theoretical framework to identify problems that can be found in mediated communication to carry out knowledge intensive activities.

2.3 A Narrow-bandwidth communication channel: a text-based CMC tool in knowledge intensive tasks

When the bandwidth is narrow and the task is complex, what can we do to stimulate collaboration among geographically dispersed team members? This question typifies communication difficulties when carrying out complex decision-centred tasks that daily occur in modern organisations.

Despite its popularity and abilities to maintain close interpersonal relationships, a synchronous spoken or voice communication medium, such as fixed-line telephone and mobile telephone, has been considered to be a less effective communication medium in remote interactions due to its sensitivity to noise, interruptions, and lack of persistency (Kjeldskov & Stage, 2003). From our perspective of group decision making by geographically dispersed team members to solve KM problems, this suggests that synchronous voice communication does not appear to be appropriate any longer.

Computer conferencing is believed to provide effective tools in mediating collaborative group work and ideas sharing, when members are dispersed in location. These conferencing systems can vary from video, text, and audio or a combination. Computer conferencing promises the cost effectiveness of the use and implementation of advanced computer conferencing tools to support main tasks. In our perspective, the text-based computer conferencing tool particularly can come close to the kind of ongoing discussions that often occur in an office, and it has the added benefit of having a written record of those interchanges (Gray et al., 1994). Thus, text-based computer conferencing has a special significance for KM for the simple reason that when a team uses computer conferencing to collaborate, a permanent, shareable, record of what they write and send to each other is created. This permanent shareable record is not created when people use other collaboration tools such as telephone or other audio and video conferencing (Gundry & Metes, 1996).

The most interesting recent development is the emergence of synchronous written communication, such as internet relay chat (IRC) and instant messaging services (IMS) that tend to penetrate gradually in the e-learning and e-business domains. Research into the effectiveness of chatting suggests that structured online chatting might be sufficient to support virtual decision-making processes (Farnham, Chesley, McGhee, Kawal, & Landau, 2000). Another investigation that compared mobile text- with voice-based communication in a safety-critical domain has shown clear advantages of text-based communication (Kjeldskov & Stage, 2003).

With the rapid development of computer and internet technology, chat and IMS offer both synchronous and asynchronous communication sessions as one technological solution. They are also relatively easy to establish, cover many users, and require narrow bandwidth data exchange. Chat and IMS, if used synchronously, may encourage quick responses with short messages. They are also believed to speed up the interaction process, but tend to increase the pressure to respond quickly (Stahl, Herrmann, & Carell, 2004). Chat and IMS can be best seen as lean media, because they do not transfer emotional and interpersonal cues easily. Those could be considered to add-value to task performance in group decision making.

According to the perspective used in this dissertation, there are always risks involved in using text-based chatting, because the message transferred in text-based CMC is somehow very poor for conveying shared meaning in group decision making. Chatting often leads to misunderstanding of the subject of conversation; hence fails to fully cover shared understanding. For CMC tools that are mostly textual, many researchers have reported on how group members make more errors than in face-to-face communication, which can happen due to poorer comprehension in CMC (Bordia, 1997). Other research done by McGuire, Kiesler, and Siegel (1987) found that textual CMC produced less argumentation compared with face-to-face communication, but the information exchange went more quickly and easily. This can happen due to fewer social restrictions and the impact of norms, conveyed by non-verbal information. We believe that, to some extent, that Chat and IMS can achieve the three conversation subtasks identified by Fussel et al. (2000).

Thus the use of text-based communication in group decision making should not be neglected because its limitations to exchange information, and vulnerability to biases and misconceptions when understanding the problem being solved. The implementation of text-based computer-mediated communication should take into account the positive aspects of chatting, like cost effectiveness. It can also add to the value of the group decision making process and a lessons-learned effect by being involved in knowledge intensive activities. When communication lacks the dynamic personal information of face-to-face communication or even of telephone communication, people focus their attention more on the words in the message than on each other (Sproull & Kiesler, 1991). Eklundh et al. (2003) reported that more than half of the dialogue in text-based chatting is focused on problem solving compared to dialogue in video and voice chats. As communication in text-based chatting is harder, therefore most of the effort is put into actually solving the task. Thus, the limitation and the benefits of text-based chatting may suggest it as a valuable activity to create lesson learned opportunities. This makes it worthwhile to be investigated, in order to understand problems of communication processes under limited bandwidth conditions and to see the possibilities to support it in the context of carrying out knowledge intensive work.

2.3.1 Potential risks of using text-based CMC tools in group decision making

Despite its ability to enable flexibility, adaptability, and speed in a dynamic global situation, virtual teams must cope with problems such as lack of trust, lack of shared background knowledge, coordination problems, problems as a result learning new ways to behave and interact, and problems as a result of missing face-to-face encounters (Huysman et al., 2003). A key question is how far we can improve the effectiveness of mediated communication in virtual group problem-solving, by using text-based chatting. Are there possibilities to compensate for weaknesses in text-based communication in group decision making? This sub-section discusses the possible dynamics of communication in group decision making in terms of how members of the team share and supply high quality information in text-based chat contexts to solve KM problems.

One of the studies done by Sproul and Kiesler (1991) showed that electronically mediated group decision making tends to produce fairly unconventional decision processes and risk seeking. The result of their study might be used as a first issue in studying the potential risks of text-based chatting in this dissertation. If we reason from this finding, it may suggest that low quality of information exchange in text-based chatting may happen at any time in complex interaction situations, such as in group decision making to solve KM problems collaboratively. This can be interpreted as that text-based chatting directly inhibits meaningful information exchange to create common ground and leads to possibly biased individual cognitive understanding of the problem being solved.

The tendency of biased perception in decision making will become more evident in a group process with narrow bandwidth communication, because the communication process will not be able to reduce bias due to its limitation to convey shared understanding. Moreover, as said before, not everybody is aware of cognitive biases in the group setting. Probably the function of many collaborative communication activities is to reduce the common biases in solving decision problems, which influence individual cognitive processes to understand the problem being solved. The function of the collaborative communication activities in reducing biased cognitive processes can be understood as a control mechanism to reach a common understanding of the problem being solved. Hence, it can contribute to better decision making processes and better solutions to the problem.

Two reasons can be given to explain the predictions above: (1) communication as a process does not necessarily produces efficient and effective processes to stimulate meaningful information sharing; (2) as a consequence of flawed communication, individual cognition will not able to comprehend the nature of the problem appropriately. This suggests that the unconventional and risk seeking decision outcomes observed, are one of the products of a biased or a misconception based reasoning process by group members involved in limited bandwidth communication in particular, and a faulty collaborative communication process in general.

According to the information exchange theory sketched in Section 2.2.3, the only opportunity to enhance text-based chatting is by providing the members of the team with high quality external information representations, which can reduce cognitive bias, ineffective (overloaded) communication processes in text-based chatting, and elicits a collaborative communication situation/setting. The potential of the computer as a medium of communication, even though the communication takes place in text mode, does increase the opportunity for the user to obtain other types of information representations containing additional information more or les simultaneously. This gives us opportunities to find technological oriented solutions that can be effectively coupled with text-based communication to support collaborative task performance. The technological solution needed should enhance the quality of relevant information to support task accomplishment and collaborative communication. This approach is not only believed to be a realistic strategy for collaborative tasks, but it is also expected to be appropriate to stimulating individual cognitive processes. We know also that decision makers tend to use information in a form in which it is presented in order to reduce cognitive effort (Tabatabaei, 2002). In the next subsection this reason for trying to enhance the quality of information is elaborated.

2.3.2 Compensating for the deficiency of text-based CMC tools in group decision making: visual information representation

From the previous section, we have concluded that supporting text-based chatting can be done by enhancing the quality of external information representation technologically. The goal of the support is expected to assist in:

1. Supporting the individual cognitive process to solve the problems by means of supplying the needed information to reduce cognitive bias;
2. Reducing inefficient communication processes that are caused by the opacity of the problem being solved – striving to find common ground for the problem;
3. Stimulating effective information sharing: selecting and distributing relevant information to the group communication process;
4. Creating a better collaborative context for analysis of the problem.

Concerning the quality of information representation as the support for text-based chatting, we are confronted with a question: how to reach a high quality of information representation that supports the above points. To approach this question, we first attempt to understand the role of external representations of information in the cognitive-fit paradigm and later broaden the cognitive-fit paradigm to the communication and collaboration process.

Poole (1978) suggests to review the task characteristics in order to determine the characteristics of information that must be extracted and exchanged by a group to accomplish a task. Matching the problem representation to the main task, is known as the cognitive fit paradigm (Vessey & Galletta, 1991). The basic idea behind the cognitive fit model is matching the type of external information required to represent the problem being solved to the internal problem representation in cognition. Cognitive-fit is a cost-benefit characteristic that suggests that, for effective and efficient problem solving to occur, the problem representation and any tools or aids employed should all support the strategies (methods or processes) required to perform that task. This means that the usual way of a problem solver to utilise the information in cognition must be considered in the context of the task to be solved. By assumption, the matching of the representation of the main task and the external information that is cognitively fitting is believed to result in a consistent mental representation of the problem that facilitates the problem-solving process. Basically, if the content of information yields relevant information to an inference, comprehension and reasoning proceeds smoothly and may even be slightly faster than with other sorts of content (Knauff & Johnson-Laird, 2002). It is pointed out that the characteristics of information representation to support group decision making processes must support the cognitive processes by any information that represents facts, beliefs, and elicit memories about the problem being solved.

The discussion of the cognitive-fit paradigm above has pointed to the need of high quality information for representing the problem being solved and the cognitive process must align. However, the cognitive-fit paradigm does not mention clearly how to reach this fit between the information and the task being carried out cognitively. Nonetheless, it is clear to us that high quality information representation should be able to avoid cognitive bias. Thus, it should be able to stimulate members of a team not just to rely on the simple heuristic principles as mentioned by Tversky and Kahneman (1974) to make decisions and solve the problem, and encourage deliberate reasoning in the group decision making process.

Broadening the cognitive-fit paradigm to group problem-solving processes, the role of text-based communication processes must be taken into account because they are at the basis of group processes that aim to reach effective and efficient solutions by utilising specific types of information representations. This is deduced from the argument that if the external information representation of the problem to be solved and the information being processed do not fit cognitively, the communication will be devoted mainly to obtain a common understanding – grounding the problem – and fails to benefit from the collective knowledge construction processes, such as identifying patterns of information, that may not be recognised by individuals and creating emergent solutions that no individual would have thought of prior to the group discussion (Propp, 1999). The problem of the incompatibility between external information representation and information being processed cognitively can occur because the shared perception of the external information that represents the problem may be too difficult to be synchronised and exchanged through communication in a text-based chatting process, due to its limitation to convey meaning. It is expected that a cognitive fit with external information will stimulate individual cognitive processes and, by implication, both group cognitive processes and collaborative communication. Huysman et al. (2003) expressed this need as having shared ideas in a virtual team as a need to obtain a common language and artefacts.

When investigating the support elements in decision making and problem solving processes, benefits of computer-based visualisation has attracted many researchers to investigate its effectiveness to present meaningful data information to support these processes. External graphical representations are of considerable importance in problem solving (Baker, Corbett, & Koedinger, 2001). In the domain of organisational theory visualisation is similarly found to be supportive to make appropriate decisions and better problem solving in organisations (Senge, 1990). Tegarden (1999) stated that visualisation technologies have been used in many areas of business and they have been used to support many different tasks, for example exploratory and confirmatory tasks. However, it is still unclear where this technology may be most effective. In term of supporting collaborative processes, Kraut, Gergle, and Fussel (2002) stated the importance of shared visual information to maintain an awareness of the current state of the collaborative tasks in relation to an end goal.

A combination of visual information with text-based chatting reminds us of an old cliché of “a picture is worth a thousand words”. However, this is not intended to be universally applicable irrespective of a given set of circumstances. There are times when it is more useful to use words and/or pictures only. There are other times when pictures are best used to discover something new (Marakas, 1999). It is not surprising that despite the potential benefits of information visualisation and other visual information representations to support problem solving and decision making, little evidence has been found to support these claims convincingly. Most of the evidence that shows the benefit of computer graphics to support effective business decisions has led to conflicting findings (Dickson, DeSanctis, & McBride, 1986).

In the next section of this chapter, the potential benefits of visualisation to support decision work, particularly in text-based group decision making and problem solving, are elaborated.

2.4 Visualisation in decision making and communication process

It is generally accepted that verbal meaning only becomes a reality when a person engages with printed words – meaning is brought into being by the interaction between reader and the document. Communication is a complex, uncertain process, and one should think about documents as if they are part of a conversation (Mackenzie-Taylor, 1999). The role of documents in a conversation is related to the meaning intended to be conveyed by a communicator. The design of documents, then, must consider the needs and actions of the communicator. We pragmatically follow this reasoning to support text-based chatting in group decision making. Logically, in text-based chatting, people loose their visual orientation as a member of a team and also a visual representation of the main problem. The former is considered less important due to its minor relevance for task completion and is considered, to some extent, as a distracting factor in group processes. The latter is considered as the most important factor in solving the main problem, because business information is different from other types of data. Business information is typically abstract, discrete, and multi-dimensional (Tegarden, 1999). Most of the support in managerial decision work considers visualisations as valuable tools for generating high quality decision making outcomes. In general, visualisation is defined as graphical presentations of data, information, or concepts. Visualisation has become an external artefact supporting decision-making. The importance of representing business data and information is a well known issue in supporting problem solving activities in daily work. Marakas (1999) stated that data mining and data visualisation approaches support decision makers to ask questions of the data previously unable to be asked and to discover new relationships contained within the data previously undiscoverable. The application of data mining and visualisation in business sectors can be found in the form of on-line analytical processing (OLAP) database systems, spreadsheets (manual and/or computer-based), charts, and other graphical information systems (for example, Oracle, The silicon graphic visualisation system, and IBM Visualizer).

A number of advantages of visualisation are listed below (Ware, 2000):

- Visualisation provides an ability to comprehend huge amounts of data;
- Visualisation allows the perception of emergent properties that were not anticipated;
- Visualisation often enables problems with the data itself to become immediately apparent;
- Visualisation facilitates understanding of both large-scale and small-scale features of the data;
- Visualisation facilitates hypothesis formation.

Brodlie et al. (1992) stated that the goal of visualisation is to promote a deeper level of understanding of the data or information under investigation and to foster new insight into the underlying processes, relying on human's powerful ability to visualise.

In educational science, visualisation, such as graphs and diagrams, supports heuristic processes in learning and decision-making because it provides ways to visualise relationships between variables graphically and providing feedback to the learners concerning consequences of their actions (Veermans, 2003). Summarising the potential function of visualisation for the decision making process, it is obvious that the function of visualisation is to produce a better understanding of the problem being solved. The missing link in discussing the benefits of visualisation is its function for group processes, how visualisation can support the process of making decision collaboratively. Following Roth, Bowen, and McGinn (1999), we also think that the use of charts and graphs have first and foremost a social function in collaborative learning. We believe that the process of knowing in collaborative learning is influenced mostly by social interactions - learning occurs when people participate in ongoing practice with peers and more competent others (Bowen, Roth, & McGinn, 1999a). Person and Graesser, (1999) mention that discourse moves such as hinting, prompting, splicing, pumping, and summarising, improve the quality of collaborative interactions by correcting misconceptions. These interactions will, to a large extent, consist of exchanging information and meaning inferred from visualisation.

Both functions of visualisation for cognition – perception and social interaction, are believed to drive the role of support elements in group decision making and problem solving. From our perspective of communication, we expect that the social interaction function of visualisation and graphical representation is to be most effective for the group communication processes and lead to better decision processes.

2.4.1 Types of information visualisation: Graphical charts versus Numerical tables

As mentioned before, business uses visualisation to make faster and more accurate decisions. The use of advanced visualisation in business has created many innovative findings and investigations. With the development of the computer and internet, large scale business information can be easily transformed into various types of visualisations. If we look to efforts to convey business information statistically, Mahon (1977) says that in order to convey statistical information we have three media: words (spoken and written), tables and pictures, usually in the form of graphs. These three components are very important in communicating findings and influencing people's decisions. Graphs, diagrams, and tables are the artefacts that people most like to use. The focus of visualisation in business information is mostly on comparing the benefits of graphs versus numerical tables in the decision making process. We took this research direction in this dissertation.

Although graphs are very pervasive and sensitive to evoke human understanding, many investigations in educational science have proved that graph creating and comprehending are not easy tasks (Bowen, Roth, & McGinn, 1999b; Carswell, 1992; Krasavvidis, 1999). They said that most of the students spent more time in plotting graphs and later needed to be stimulated to comprehend the graph. However, once students can take advantages of spatial grouping in the charts, they will improve their free recall and hence improved their learning processes (Braden, 1996).

Senn (1995) stated that the use of both manual and electronic spreadsheets/numerical tables in business organisations is to record much numerical information, summarise raw data and produce information for the analysis of organisational performance, improve organisational planning, simplify control processes, improve communication and motivation, and help managers to make decisions. Hence, it will increase managers' productivity. This is not too surprising because a numerical table display can convey very detailed and different numerical information. We know that the use of numerical tables is also commonly found in scientific reports that give quantitative information to the readers. One of the drawbacks in using numerical tables is commonly seen as them being too detailed and less effective in giving qualitative and spatial information about the data.

A study conducted by Remus (1996) pointed out that nowadays vendors of computer equipment have suggested that graphical displays help managers to understand and use data better than older ways (for example, tables of data). However the empirical literature does not support this argument convincingly. The study by DeSanctis (1984) reviewed a total of 12 studies which have pointed out that a numerical table is better than graphical representations. She also found that there was no significant difference between these two presentation modes in 10 studies and only 7 studies could show that graphical representations outperformed tables. She argued that researchers need to identify the conditions under which graphs outperform tables as a presentation medium. Since this review, several researchers have come to the conclusion that graphs should be used when people have to use their judgment to analyse trends and make forecasts (Coll, Coll, & Thakur, 1994).

Generally, the comprehension of numerical tables and charts can be approached from two different perspectives: a physiological perception approach and a semantic approach. The latter, seems to be more appropriate for the role of visual objects in group processes. According to Ware (2000), visualisation is about diagrams and how they can convey meaning. Diagrams are generally held to be made up of symbols, and symbols are based on social interaction. The meaning of a symbol is normally understood to be created by convention, established in the course of person-to-person communication. Diagrams are arbitrary and are effective in much the same way as written words are effective. Thus, one diagram may ultimately be as good as another; it is just a matter of learning the code, and the laws of perception are largely irrelevant. Ware suggests that the law of physiological perception in comprehending visual objects is often over-ruled by the semantic function of the visualisation to convey meaning. This can be explained as follows: the comprehension of either numerical tables or charts is often done on the basis of cognitive and social demands, for instance in the process of persuasion and negotiation, rather than to comprehend whether the number or data points are understandable by perception.

Bertin (1983) says that a graph is considered to be spatial-related information. Ehrenberg (1977, 1978) said that graphs are widely thought to be attractive and easier for the reader than tables of numbers and they could be outstandingly good at showing up large differences or simple qualitative features of the data (for example, whether a relationship is linear or curved). But they tend to be far less effective for communicating quantitative detail than a table. As we also know, graphs do not directly emphasise information on discrete data values as tables do. Many complex graphs are difficult to read because the eye has to move a great deal, requiring us to remember what we have seen. Hence it overloads short-term memory. According to Mahon (1977), it is broadly accepted that tables are best for indicating values and graphs for indicating relationships.

Tables are symbolic problem representations in that the information represented in them is symbolic in nature. Discrete data values are the only type of information directly represented in tables. Tables represent information about relationships only indirectly (Vessey & Galletta, 1991). Correspondingly, spatial tasks, namely associating and perceiving relationships, are better supported by graphs. On the other hand, the tasks that are better supported by a table are symbolic tasks that involve extracting discrete, and therefore precise, data values.

Generally, graphs in graphical displays of a computer are a powerful tool and can produce a quick and effective display of information for communication and analysis. The major problem in their use is that they do not always communicate the information from the data accurately. It is possible to deliberately mislead the reader (Rangecroft, 2003).

In summary, both graphs and tables may support specific tasks. It cannot be easily concluded that one is superior over another for every type of task. Thus, there is always a trade off between a well design table and a well design chart for certain types of tasks; both of them may support each other to promote a full understanding of data generated by a process or a model. It is interesting to see how group communication processes can be influenced by the representation of external information by means of numerical tables versus charts.

2.4.2 Linking decision making processes to visual representations: Charts versus numerical tables

From the previous section is has become obvious that there are differences in types of information conveyed by charts and a table. It is expected that this type of information will influence the cognitive processes and communication processes of group decision making. We agree with Fisher (1974) who says that without doubt statistics, analogy, and test of quality and quantity of evidence serve the ability to think critically which is an asset of idea testing as an integral part of group decision processes. This theory believes that decision making has a better likelihood to produce appropriate outcomes, if the actor is able to infer the potential solution by quantitative numerical statements. This suggests that a numerical table fits the deductive validity of cognition. However, this might not be true when the cognitive processes in knowledge intensive activities in performing KM collaboratively have to deal with incomplete information and a fuzzy problem.

Referring to this type of problems that humans tend to be confronted with in decision-centred work in an enterprise, where information is often incomplete and there are multifaceted solutions, more doubt can be expressed that deductive reasoning is the only way to achieve appropriate decision processes and outcomes. Simon (1977) also points out that decision making processes are not always rational, and decision makers often possess incomplete and imperfect information. It is found that there is a tendency that human reasoners are seldom interested in deductive validity. They often lack sufficient information to reach a valid conclusion, and so are forced to go beyond information given and to make an induction (Legrenzi, Girotto, & Johnson-Laird, 1993). Erev and Cohen (1990) said that "forcing people to give numerical expressions for vague situations where they can only distinguish between a few levels of probability may result in misleading assessments". Moreover, if we look back to the nature of communication in group decision making use of text-based chat, the capability of human interaction in this context to carry out complex deductive reasoning in their verbal information exchange, was explicitly questioned (see section 2.2.3).

Problems being solved in naturalistic decision making are mostly ill-defined, such as in politics and management. The best approach to facilitate the process of making decisions is by considering the qualitative translation of judgments. This theory adopts the principle that human tends to process information verbally and words are perceived as being flexible and less precise, with various communicative functions and, therefore, seem better suited to describe vague options and characterise imprecise beliefs. Laricev and Brown (2000) mentioned that this qualitative model rationality does not use values as translations of judgments, but tries to structure the problem by using the natural language commonly used by parties involved in the decision process and/or other potential experts. The goal of structuring is to define the main factors or criteria that could be applied for the evaluation of decision options initially given. For each criterion, a scale for the evaluation is constructed with a small number of quality grades. Some verbal expressions taken from language are used to describe quality grades ranging from best to worst (for example: "no damage", "moderate damage", and "great damage"). This means that only the logical consequences of qualitative relations between verbal evaluations are used in the process of making decisions. This verbal qualitative model is believed to serve communication more directly, because the sentences taken from the language used by the decision makers comprise the verbal quality grades on the criteria scales. The verbal approach is also well adapted to reality. This means it does not require from either the parties or the expert any prior knowledge of decision methods. The decision method is a completely natural tool for the user, and is adapted to ways of information exchange pre-existing within and between organisations.

It is expected that the verbal approach serves collaborative communication reasoning more directly because the sentences taken from the language used by the parties and active groups comprise the verbal quality grades on the criteria scales and makes it possible to be passed through the text-based communication channel. Thus, this suggest that the information representation conveyed by charts and diagrams is best suited to the characteristics of the group decision making process in solving KM problems that is mediated by text-based computer communication and will lead to a better decision making process and better learning KM in collaboration.

2.5 Concluding remarks

In the first chapter, we stated that learning KM is needed to facilitate the shift of work characteristics to decision-centred work. KM is predicted not only to supply new knowledge but also problem solving skills. Considering the work situation and the requirement of learning KM as problem solving skills, in this chapter we stated the rationale of learning KM in collaboration which is a characteristic of carrying out knowledge-intensive tasks. It was also mentioned that providing opportunities for learning KM in collaboration requires an instructional solution. Gaming and simulation are assumed to create the opportunity for learning KM in collaboration in a learning organisation setting. As a process of interaction, communication, by nature, stays complex and it is predicted to be the key to collaborative interaction in worker – knowledge sharing activities. Communication as a process of interaction has many obstacles: narrow medium, difficult sub-tasks (decision making and problem solving phases). Communication as a representation of information sharing activities must be supported. This support can be partly achieved by visualisation of information.

Visualisation is believed to provide two types of numerical information to the group decision making process: quantitative – symbolic and qualitative – spatial information. Taking information visualisation in the form of spreadsheet tables versus graphical charts as a design challenge in visualising business information, we predict that graphical charts will be more effective to support the process of communication in collaboration when learning KM than charts. The reason is because the spatial information, as present in charts and diagrams, will fit better with the requirements of the communication processes that are related to collective cognitive processes while sharing information in learning KM collaboratively.

The consequences of inadequately supported information exchange between people in narrow-bandwidth computer mediated communication with information visualisation will be indicated by: (1) low quality and quantity of communication - participation, information exchange, and other particular types of message; (2) inefficiency in the use of expenditure and in use of time; (3) a low quantity of decisions; and (4) member dissatisfaction with the decision making processes; (see Scott, 1999). As a result of this, low levels of learning outcomes for KM are to be expected.

At this point, the central topic of this dissertation: “Supporting information exchanges between people in narrow-bandwidth computer mediated communication with visualisation of numerical information while they perform group problem solving and decision-making collaboratively” has been approached theoretically.

Obviously, the above theoretical framework and the predictions must be investigated empirically. To conduct empirical studies on this main problem, we have to design and implement the visualisation in a collaborative computer-based learning environment that uses simulation and gaming to teach KM.

In the next chapter, the visual design rationale together with a detailed description of the KM Quest gaming simulation for KM training, as an instance of the targeted learning environment will be presented.

3 Design and Implementation: Simulation game and visualisation

The focus of this chapter is about how the information visualisation that meets the characteristics of spatial and numerical information is designed. However, as mentioned before, we can not take up the design strategy for information visualisation without first elaborating the KM Quest game simulation that is used as the instructional solution for collaborative learning of KM. The KM Quest game system will be described in particular on how this simulation game provides a collaborative situation in the decision centred work and how it meets the need of learning KM as a fuzzy and complex domain.

The major part of this chapter is about applying visual design principles to the numerical information from the game indicators. This numerical information is intended to support the process of problem solving and decision making in KM. However, while thinking about and considering the design strategy, we carefully take into account the needs of people in the decision making and problem solving process in the context of business and knowledge management in the real world.

This chapter consists of two main parts: a description of the KM Quest gaming simulation system, and the visualisation of the game and its information.

3.1 KM Quest^{TM}: KM interactive and collaborative training

3.1.1 Introduction

In the previous chapter, it was claimed that simulation and gaming can support organisational learning and also provides the context of learning KM in collaboration. This assumption is not too surprising, because when we look to the history of business and management training, gaming and simulation have been known as very potential methods to develop business skills and understanding. The first business game was produced by the American Management Association in 1956. This game was a decision making simulation exercise for business executives. Led by the Harvard Business School, which made the case-study method one of the foundations of its teaching, the use of business games soon spread to business schools throughout the world (Ellington & Early, 1998).

Carson (1969) gives three characteristics of business games:

- Business and management games are *simplified mathematical abstractions* of a situation related to the business world. The game participants, either individually or *in groups*, manage a whole firm or an aspect of it, by making business decisions for successive periods;
- A business simulation game may be defined as *a sequential decision making* exercise structured around a model of business operation, in which participants assume the role of managing the simulated operation;
- Business games are case studies with *feedback and a time* dimension added.

In the context of KM, some professional organisations and scholars in KM have tried to use a simulation and gaming approach to teach KM. Between 1994 and 1997, the Celemi company in Sweden (www.celemi.com) developed a board KM game called TANGO!^{TM}. Later this KM game was marketed in the computer-based version with the name of Tangonow (www.tangonow.net). An attempt to use a gaming approach in teaching KM is described by de Hoog et al. (1999). In their study using a KM game, they supplied a business case and events to the players through websites and e-mail connections. The players had to solve them collaboratively. Human instructors who are experts in KM were used to evaluate the process of playing this game. The interaction between players and instructors was maintained by e-mail. The results showed that the use of gaming techniques to teach KM was very promising, but it was suggested that an automated, systematic, and validated feedback mechanism is required to evaluate players' behaviour during the course of playing and learning. This suggests that to support player's understanding a strong simulation component is required in a KM game system.

From 2000 onwards, KM Quest[1] (www.kmquest.net) was developed in a research project called KITS (Knowledge management Interactive Training System). This project was funded by the European Commission. The main goal of the project was to develop an internet-based game platform for teaching KM in business domains. The game system is targeted to support geographical dispersed learners as well. The main target users are experienced managers who are keen to learn more about or practice KM and are responsible for the implementation of KM in their organisation. Other target users that might pay attention to this game are university or business school students who want to know more about KM. Our research interest has led us to pay more attention to the latter target users because this group may be used as a model of novice users or managers, who are in a transitional situation between conventional management work and decision-centred work which requires knowledge-intensive tasks.

KM Quest is developed with the intention of providing collaboration, situatedness, and authentic opportunities for learning KM in business. The intention is not only to introduce KM as a domain to be learned conceptually only, but also for strategic problem solving and decision making strategies. Two learning goals to be achieved after playing with KM Quest are (Leemkuil et al., 2003; Leemkuil et al., 2001):

1. Learn and practice a (general) systematic approach to problem solving in the KM domain. The type of knowledge to be acquired is strategic knowledge. Strategic knowledge describes goals or control structures that characterise the performance of experts or competent task performers;

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[1] KM Quest™ has been developed through the KITS project which was partly funded by the European Commission under the Information Society Technology (IST) RTD program, Contract No. IST-1999-13078 (http://www.cordis.lu/ist). For more details please see http://www.kmquest.net.

2. Learn KM conceptual knowledge. Conceptual knowledge consists of related concepts and principles. In principle, having KM conceptual knowledge means that players know:
    - Performance of business and KM indicators;
    - KM problems and opportunities;
    - KM actions and interventions;
    - Translation of performance (business and KM) indicators into KM problems or opportunities;
    - The relations between KM problems or opportunities and KM interventions;

The effects of KM interventions are on performance (business and KM) indicators. To realise this, the design of the game intentionally combines the elements of a simulation, a game, and a business case to provide a powerful learning environment. In the next sections, KM Quest is described in more detail

3.1.2 The definition of KM Quest simulation game

In our perspective, as an interactive training system KM Quest should be able to create an authentic learning environment to teach KM in business domains. As previously mentioned in section 2.1.4, both simulation and game approaches might serve the goal of learning KM in collaboration.

According to Jacobs and Dempsey (1993) and Gredler (1996), both games and simulations have some kind of underlying model that allows actions to be taken by the learner, and constraints under which these actions should take place. Games usually add to some kind of competition characteristics, participants need to reach a kind of goal state, and they quite often have to do so with a limited set of resources. The game characteristic is believed to add to the value of simulation elements that often only represent central features of ongoing realities and situations (Ellington & Early, 1998). Another aspect of games is that they usually generate a rich interaction between the players, systems, and social environment. According to Kriz (2003), a combination of simulations and games simulates actors' decision making processes and demonstrate the consequences of decisions within social systems, for instance within a company. He defines the combination of simulation and games as the simulation of the effects of decisions made by actors assuming roles that are interrelated with a system of rules and with explicit references to resources that realistically symbolise the existing infrastructure and available resources.

Above statements suggest that KM Quest may benefit from the combination of aspects of games and simulations. However, we think that beside the added value of games to simulations, a simulation games require an element of case studies to provide players with a more realistic social system. According to Van Merriënboer (1997), case studies will describe a spectacular event in order to arouse the learner's interest: an accident, a success story, a disputed decision that turned out all right, and so on.

Figure 3-1. Game, simulation, and case study.

Figure 3-1 shows that game, simulation, and case study are interrelated to each other and the location of KM Quest (see (X) in Figure 3-1) is in the intersection of all three: game, simulation, and case study. This combination is expected to create rich collaborative learning opportunities, challenging to the players, and provide meaningful knowledge about KM. Thus, KM Quest as a simulation game system combines the elements of: playing under constraints (rules), limited competition (playing against the system instead of against players), a realistic and dynamic underlying model as in simulations, and case studies. The competition element in KM Quest is limited, which means it is directed against the system or "nature" instead of against competing teams, due to the functional purpose of learning with simulation games that is aimed at learning the consequence of player's decisions from the environment.

3.1.3 The architecture of KM Quest

The KM Quest environment was designed based on the operational model of cyclic functioning of KM presented in Chapter 2 (see Figure 2-1). The rationale behind the architecture is (1) to support the achievement of the two learning goals mentioned in section 3.1.1 and (2) to provide understanding about the generic model of KM activities in an organisation (see section 2.1.1). The conversion of this cyclic model to the system design is shown in Figure 3-2.

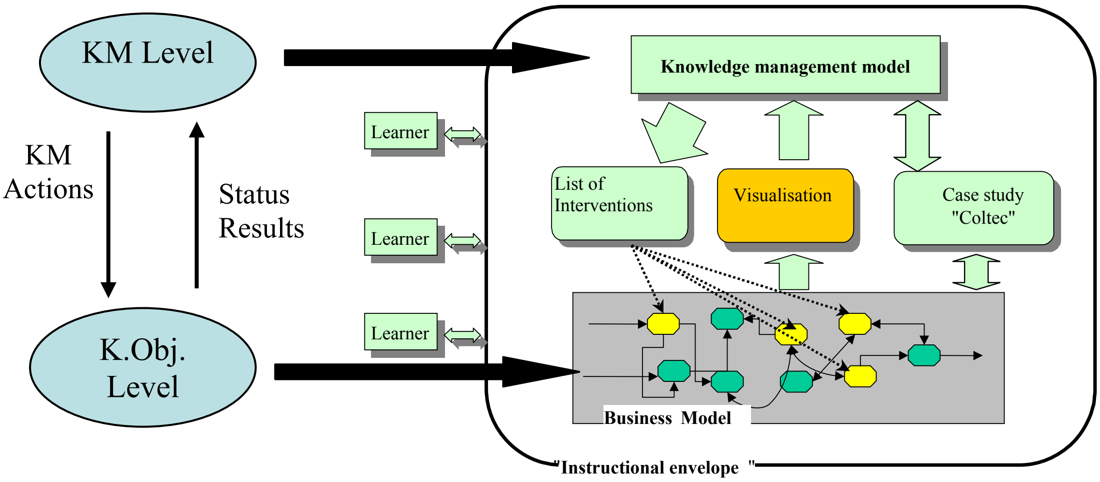


Figure 3-2. The architecture of KM Quest.

As shown in Figure 3-2, there are three main components that form KM Quest: (1) a knowledge management (KM) model, (2) a business model (BM), and (3) an instructional envelope. Each component has its own function, but the combination of them is expected to create constructive and collaborative KM learning processes. This figure also shows three intermediate components: the list of interventions, visualisation, and the case study of "Coltec" (see also Appendix A, B, and C). As visualisation is the main topic of this dissertation, it will be described in a separate section (section 3.2).

In the next sub-sections, each of the game components is described briefly.

3.1.3.1 The knowledge management (KM) model

Based on the professional experience of KITS project partners who are extensively involved in KM consultancy, the following KM model is used in KM Quest. As explained in the section 2.1.1, the need of for a KM model to provide players with a generic problem solving strategy is crucial. The KM model is intended to guide players to shape their strategic KM problem solving skills in the course of collaborative learning. Therefore, the acquisition of this model is the main target of the playing process.

To emphasise the acquisition of the model, the game provides the KM model at two different level of abstraction: (1) A general abstract model and (2) a detailed procedural model.

Figure 3-3 shows the KM model used in KM Quest. This presentation of the KM model is general and rather abstract. The players have to be able to follow the flow of this model while solving KM problems collaboratively.

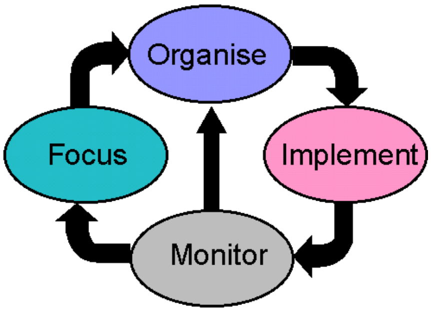


Figure 3-3. The problem solving strategy: the abstract model of KM.

This abstract model is chunked systematically into a more detailed procedural model in order to teach players following the model. Figure 3-4 shows the result, a detailing of the abstract model of the KM problem solving strategy. By following the path in this model, it will guide players step-by-step to understanding sub-tasks in each step of the KM problem-solving strategy.

The sub-tasks of the KM model consist of problem-solving tasks that require information taken from the game indicators. For instance, in the first sub-task of the "Focus" phase, inspecting current Business Process indicators (BPI) values and event, it is expected that the game indicators that are relevant to this sub-task become the crucial information to support the accomplishment of this sub-task. The same holds for other sub-tasks, such as in “obtaining information on knowledge processes”, “determining the desired BPI values” and so forth. It is believed that the visual representations of the game indicators support the performance of these sub-tasks.

It is also expected that the flow of the playing process will be guided by the instructional envelope. Although the instructional support does not rigidly forces the players to follow every single step of this model, they are expected to follow cues and are advised to do so.

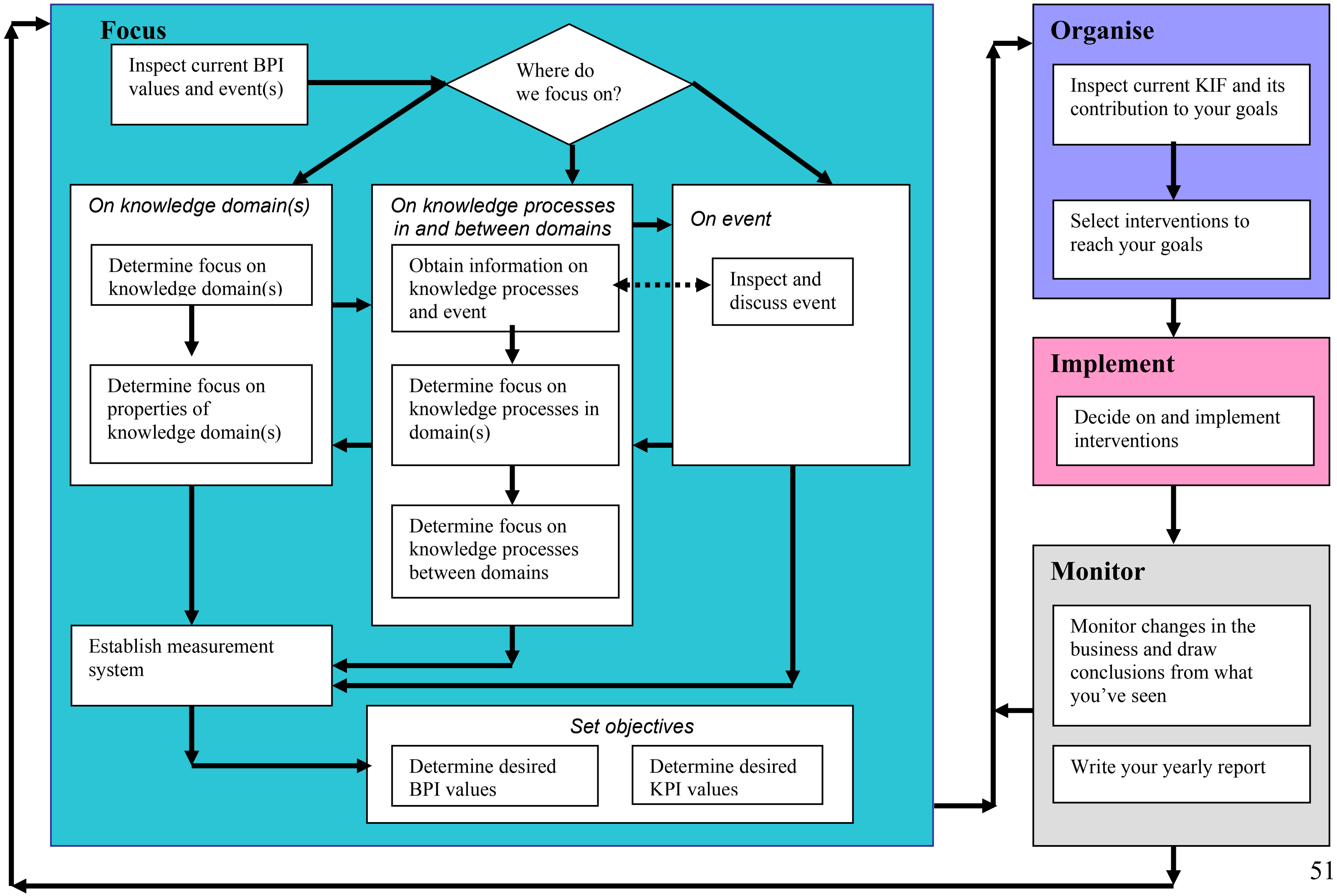


Figure 3-4. The detailed KM model.

3.1.3.2 The business model (BM)

Briefly, the role of the business model in the game is to represent the behaviour of the organisation (and to make the business case description lively and dynamic) and also to provide players with problems and situations that are commonly found in the real working situation. Characteristics and states of the organisation, and similarities with organisational situations, are the crucial factors that must be taken carefully into account when modelling the business process in order to provide situated learning opportunities.

The decision to model a prototypical organisation was based on the organisation type of a product leadership company, as defined by Treacy and Wiersema (1995). The main characteristic of this type of organisation is that the company competes by bringing innovative products to the market rapidly. This implies short product life cycles and innovative research and development in producing goods. We notice that this type of organisation is relevant to learn KM domains in terms of providing a learner with a credible representation of decision-centred work. From the implementation perspective, modelling this type of organisation is also somewhat less problematic because it does not need to handle complicated production processes or customer relationships, but focuses on products as entities and less abstract processes to generate them.

The main features of the product leadership organisation are (De Hoog et al., 2002):

1. Focusing on the core processes of invention, product development and market exploitation;
2. A business structure that is loosely knit, ad-hoc, and ever changing to adjust to the entrepreneurial initiatives and redirections that characterise working in unexplored territory;
3. Management systems that are results-driven, that measure and reward new product success, and that do not punish the experimentation needed to get there;
4. A culture that encourages individual imagination, accomplishment, out-of-the-box thinking and a mindset driven by the desire to create the future.

Based on the above characteristics and principles, a business model was build of a fictitious chemical company called Coltec, which produces adhesive substances and paints.

The modelling of the business activities and the dynamic states of Coltec was initially done by defining several numerical variables and their specific characteristics and next defining the dynamic relationships between the variables. The variables were grouped into two main categories: (1) visible; and (2) hidden. The visible variables are those that are directly observable for the players and are expected to be used in the playing process. The hidden variables are completely concealed, but they either directly or indirectly modify the status of the visible ones.

Generally, each variable in the categories is uniquely inter-connected based on mathematical functions with a decay factor. The decay factor will influence the variables of the BM if players do not take any actions. The value of relevant variables will be decreased over time. The main architecture of the BM is presented in Figure 3-5.

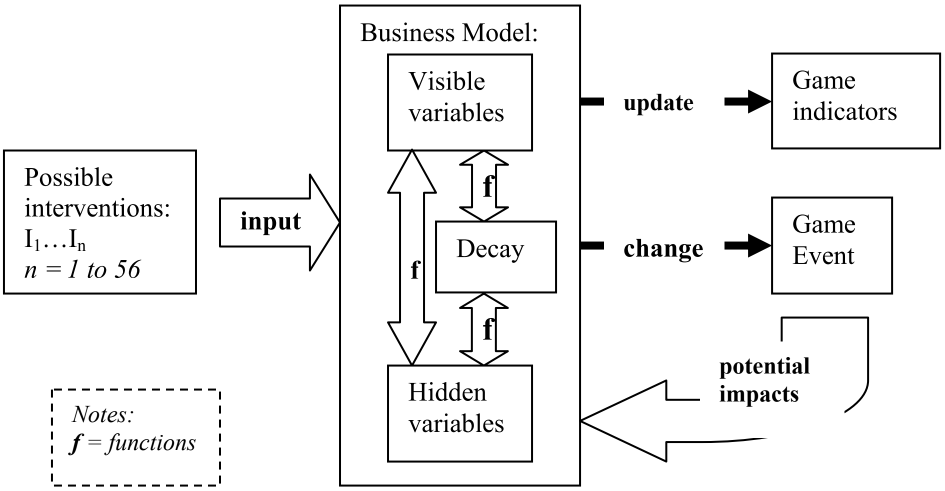


Figure 3-5. Main architecture of the BM.

As depicted in Figure 3-5, the visible variables are the main indicators of the company which can be used as relevant information to support players' playing process – deciding on KM interventions collaboratively.

Within each variable category there are a number of variable groups, see Table 3-1 for a detail overview.

Table 3-1. Specification of groups of variables in KM Quest.

Category	Type	(N) Variables
Knowledge processes related variables	Visible	39
Knowledge related variables	Visible	3
Business processes related variables	Visible	15
Organisational effectiveness variables	Visible	25
Sub-total		**82**
Input variables, changed by KM interventions or events	Hidden	17
Constant and non-visual state variables	Hidden	58
Case variables	Hidden	12
Sub-total		**87**
TOTAL		**169**

As mentioned before, the visible variables are what we will further call the game indicators. They are considered as very crucial information in the playing process and are also important as business data information to support managerial decision making in reality.

Architecturally, the visible group of variables, are computed based on hierarchical connections between its subgroups. These connections propagate the impacts of each layer (group of variables) to the next one in a particular way. Figure 3-6 displays general propagation of the values according to the hierarchical connections between groups of visible variables. This propagating process is influenced by the hidden variables and decay factors.

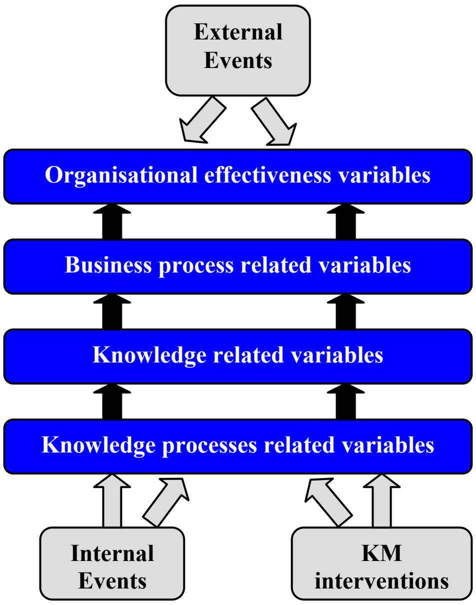


Figure 3-6. The construction of the BM.

As depicted in Figure 3-5 and Figure 3-6, the BM can be changed by two factors: a selection of KM intervention(s) and the game events (internal and external). However, the effects of these two factors on the indicators are located differently. The interventions and internal events have an impact on the knowledge process related variables; the external events influence the organisational effectiveness variables.

In general, when a set of game interventions is submitted to the BM, it is conditionally checked on potential impacts on the availability of events and the BM variables. This process triggers mathematical calculations to change the status of indicators and at the same time selects a new game event. This cyclic process of input, processing, and output is influenced by results of the collaborative playing process – collaborative decision making on selecting KM interventions to solve KM problems. It is intended that the feedback from the BM, as the result of this cyclic iteration, provides learning opportunities.

One can imagine that playing the game collaboratively while considering all 82 indicators which are presented in numerical variables (see the details in Appendix A) is complex and problematic. In the previous chapter, it was said that the problem may be aggravated by the complexity of the communication process, the different characteristics of the variables, the complexity of the network of the variables, and the limitations of human information processing capacity. It was also said that the numerical information concerning the business processes is commonly known as being abstract, discrete, and multi-dimensional (Tegarden, 1999). This makes it unrealistic to expect players to consider all variables in the playing process. However, playing with taking only a limited number of variables into account is also less optimal. Given this problem, it is a real challenge to design meaningful support artefacts that can help players to achieve a solid understanding about the underlying model behind the game while players involve in the collaborative communications, especially ones that emphasise the meaningful relationships of a limited set of variables.

As explained in the previous chapter, the complexity of visible numerical variables for the game indicators can be reduced by visualisation (charts and numerical tables). This central design problem of visualisation will be elaborated and defined in detail in the section 3.2.

3.1.3.3 The instructional envelope

The instructional envelope covers the association between the KM model and BM in the playing process. The function of the instructional envelope is mainly to support and mediate the players' interaction with the game system. It is strategically defined to facilitate the playing and collaborative learning process. The instructional envelope has three main elements: (1) the game and its rules and objectives; (2) communication support tools; and (3) instructional support tools. Below, these elements are elaborated briefly.

The game, the rules, and the objectives

The description of business case and events

As mentioned earlier, the business case used in this game describes a fictitious company called Coltec (De Hoog et al., 1999). This company is a manufacturer of adhesives, coatings, and etcetera. In this business case, extensive information about Coltec – its history, current business state, organisational diagram, and the operational strategies, is described (see also Appendix B).

To promote activities from the players and to make sure that players are confronted with different types of KM problems, at every quarter an unexpected event is triggered. The events can affect the knowledge household or other business variables of the company. An event is presented in the content of "Coltec News" (see the game interface in Figure 3-9). Events are, partly randomly, selected by the BM from a collection of 50 events.

The game interventions

The game interventions are given to the player as a list of 56 possible KM interventions (see also Appendix C). This list of predefined game interventions represents common KM interventions in organisations. The players may select more than one intervention in each game quarter. Each intervention has its own price, which forces players to select multiple interventions carefully. The intention to give this list is to limit the action space of the players in the playing process. There are two reasons for this. First, by reducing the scope and number of interventions the game stays playable. Too much freedom will cause floundering behaviour. Second, to keep the behaviour of the BM traceable as an infinite number of interventions is impossible to model.

The rules of the game

The simulation game is played by three players, who have to work collaboratively as a team of hired managers. The playing phase consists of 3 consecutive years or 12 quarters in the life span of the company. The main task that they have to carry out is to improve the state of the Coltec Company by improving its knowledge household.

The role-playing technique is integrated into the playing process. As mentioned before, when entering the game the players will be confronted by the case descriptions and a triggered game event. In the process of playing, players can inspect the status of business and knowledge related indicators given by the BM, they can search for additional information, discuss their analysis, try to decide on a set of potential KM intervention(s), and when they reach an agreement on the selection of KM interventions, they can submit the interventions and the game system will show the next event and the new status of indicators. This cyclic process is repeated over and over by teams until the game reaches the final quarter.

The decision making process to solve the KM problem is recommended to follow to the procedure of the KM model. It is expected that the players will follow the procedural steps and its sub-tasks of the KM model as mastering this model is stated as the main learning goal of the game (see Figure 3-3 and Figure 3-4).

The process of selecting and deciding on a set of KM intervention(s) is constrained by a limited game budget. In the beginning of the game each team receives 3 million (virtual) euros, which can be invested to purchase the KM interventions. There is no additional game budget during the course of the game. This creates a situation where players have to decide economically which interventions are likely to be more appropriate and efficient to solve the given problem.

Communication tools

The collaborative communication among players is supported by a text-based chat system. There are two types of chat systems: general chat and topic related chat.

The general chat is located in a separate window (see Figure 3-8), this window can be opened by pressing the chat-box icon on the task-bar or the telephone icon in the main interface (see Figure 3-9).

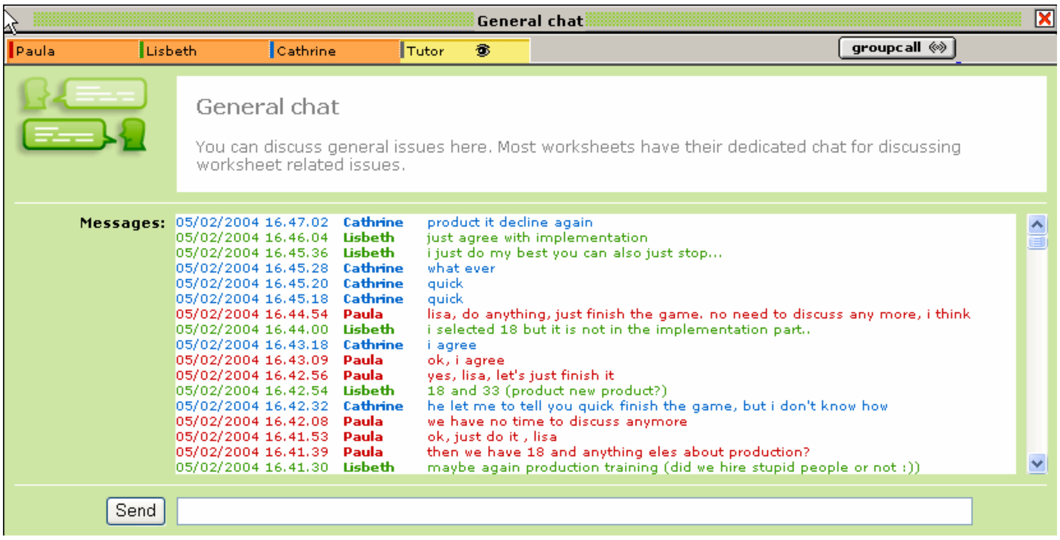
The topic-related chat system is embedded in almost every worksheet of the KM model sub-tasks (see the example in Figure 3-10). The reason to have a separate topic-related chat system is to help players to focus together on the task at hand without the need to specify this explicitly every time. In this way communication can become easier with less overhead.

In order to simplify for the players the communication in different sections of the game, the chat system is equipped with a group-call or follow-me button (see Figure 3-7). If a player presses this button, the system will notify the other two players that their team member wants them to go a specific section of the game (worksheet). With this follow-me system, each player can invite each other to go to a certain page or window which may be important to look at. If the other players also want to go to that location (worksheet), they can indicate this, and the system will automatically open the associated window on their screens. This facility greatly contributes to the ease of collaborative navigation in a system with over 100 web pages.

Figure 3-7. The group call button.

Both chat systems support synchronous and asynchronous communication. In the case of an asynchronous playing process, the chat server always keeps the delayed messages and follow-me invitations, and holds the delivery of the follow-me notification until each individual player is online again.

These communication tools follow the principle of "workspace awareness" (Gutwin & Greenberg, 1999) that is aimed to support collaboration among players. The workspace awareness helps people to coordinate tasks and resources, move between individual and shared activities, and provides a context in which to interpret other's utterances and allows anticipation of other's actions.



General chat

You can discuss general issues here. Most worksheets have their dedicated chat for discussing worksheet related issues.

Messages:

```
05/02/2004 16.47.02  Cathrine   product it decline again
05/02/2004 16.46.04  Lisbeth    just agree with implementation
05/02/2004 16.45.36  Lisbeth    i just do my best you can also just stop...
05/02/2004 16.45.28  Cathrine   what ever
05/02/2004 16.45.20  Cathrine   quick
05/02/2004 16.45.18  Cathrine   quick
05/02/2004 16.44.54  Paula      lisa, do anything, just finish the game. no need to discuss any more, i think
05/02/2004 16.44.00  Lisbeth    i selected 18 but it is not in the implementation part..
05/02/2004 16.43.18  Cathrine   i agree
05/02/2004 16.43.09  Paula      ok, i agree
05/02/2004 16.42.56  Paula      yes, lisa, let's just finish it
05/02/2004 16.42.54  Lisbeth    18 and 33 (product new product?)
05/02/2004 16.42.32  Cathrine   he let me to tell you quick finish the game, but i don't know how
05/02/2004 16.42.08  Paula      we have no time to discuss anymore
05/02/2004 16.41.53  Paula      ok, just do it , lisa
05/02/2004 16.41.39  Paula      then we have 18 and anything eles about production?
05/02/2004 16.41.30  Lisbeth    maybe again production training (did we hire stupid people or not :))
```

Figure 3-8. The general chat tool.

Figure 3-8 shows that three players were communicating textually in the general chat tool. As said before this chat tool mediates only textual conversation, thus players have limited opportunities to convey the meaning in the textual information exchange. We can see that the textual information embedded in chat is a lean medium to transfer interpersonal messages, such as emotional and social reactions but it can represent the natural spontaneous flow of conversation. The textual information is the only reference point in coordinating the collaborative communication between players in the playing process.

Instructional support tools

To support the collaborative interaction and playing process, some instructional support tools are implemented in the game. The type of tools varies from providing information resources - such as books (see number 6 in Figure 3-9), and game help;

to tools that support collaborative communication and game actions specifically – such as the process worksheets.

An instructional support to prepare the players before entering the real game is a training module. This training module uses an expository approach, which means that information on how to use the process worksheets and other game features is presented step-by-step as “assignments” to the players at certain points of time (Leemkuil et al., 2002). The environment of the training module is similar to the real system with the exception that the training process is done individually.

Three other instructional support tools are elaborated below.

The User-Interface

The user-interface contributes to the consistent of “look and feel” of the game platform. The consistency of the interface is very crucial for performing cooperative and collaborative tasks. The main metaphor of the interface design is based on a similarity with an office work space. Despite the fact that the interface is designed in a 2-dimensional environment, it is believed that this design theme is intuitive to understand for the players and will create a feeling of being in an actual work context.

The main interface of KM Quest is shown in Figure 3-9. The interaction of players with the system is by clicking on the important objects presented in the interface. Each click will open a new window. There is no limitation in opening the number of windows. Each window has a predefined size, so sometimes scrolling is necessary.

Another important characteristic that is implemented in the game interface is the flexibility for the players to open different windows. When three players are interacting synchronously, they are free to open any window. As an indication that one or more players are opening the same window, an “eye” icon appears close to the name of the player in the window task bar (see top part of the window in Figure 3-9).

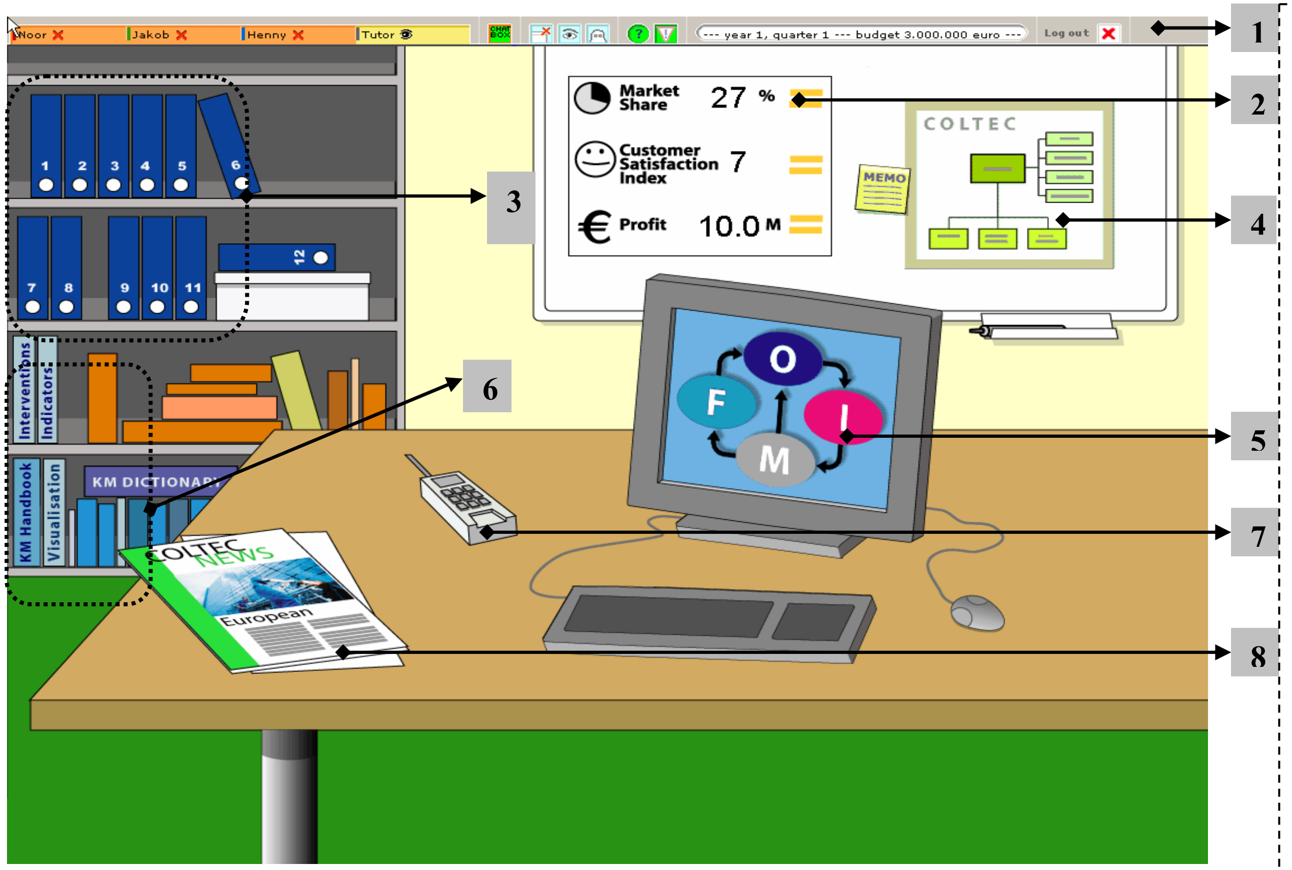


Figure 3-9. The interface of KM Quest.

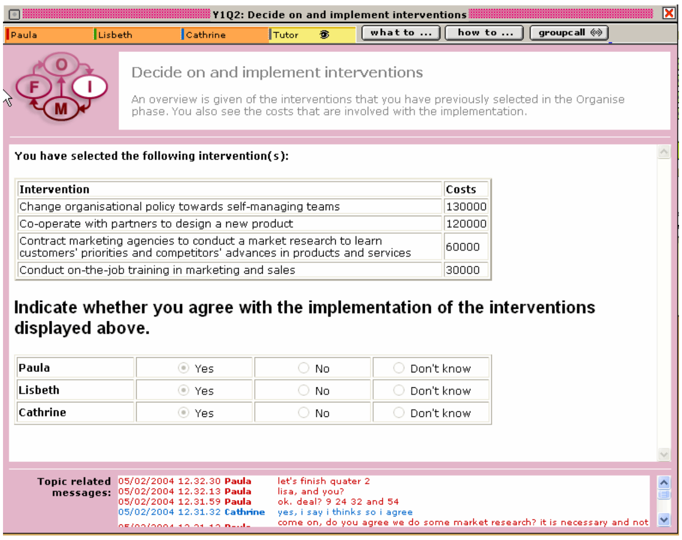
1. The game task bar: this bar shows members of the team, the link to the general chat, help, windows management, system advisor and game information.
2. The visualisation menu: this display is updated in every quarter to give information about the main game indicators. This is also a link to access the full list of visualisation packages.
3. The archives books: These books display past actions of players in every quarter.
4. Coltec information: This is the link to access the case description. It gives full information about Coltec.
5. The KM model: This is a link to display the complete KM model (see Figure 3-4).
6. Information books: These books give all information related with the content of the game.
7. The general chat: this is the link to access the general chat window.
8. Coltec news: This is the link to access information about the current event and feedback on the previous event.

The system advisor

Among other instructional tools, the system advisor is a rather unique tool because it keeps monitoring and observing the values of a set of particular game indicators during the playing process. When these values drop below a predefined level, the advisor will provide advice. The advice is given as a suggestion to submit certain types of game interventions associated with a certain set of game indicators. The indication of the system advisor is a flashing icon in the game task bar (see number 1 in Figure 3-9). This icon will attract the player to click on it and open a new window in the interface that contains the advice.

The voting tool

This tool is implemented in the "Implement" sub-task in the KM model (see Figure 3-3). With this tool players have to express their agreement with the set of interventions that are going to be implemented. Using this voting tool, the players can see the selected interventions and state their (dis-)agreement to reach a decision about the selection of intervention(s) (see Figure 3-10). As long as a player has not agreed with the selected interventions, the playing process is "frozen". One can see that the voting tool enforces players to real decision making processes as every player has a veto right that can block progress. The voting tool is the key to changing the status of the BM and its variables, and moving to the next game quarter after all players in a team have agreed with the selection of the intervention.



Decide on and implement interventions

An overview is given of the interventions that you have previously selected in the Organise phase. You also see the costs that are involved with the implementation.

You have selected the following intervention(s):

Intervention	**Costs**
Change organisational policy towards self-managing teams	130000
Co-operate with partners to design a new product	120000
Contract marketing agencies to conduct a market research to learn customers' priorities and competitors' advances in products and services	60000
Conduct on-the-job training in marketing and sales	30000

Indicate whether you agree with the implementation of the interventions displayed above.

Paula	● Yes	○ No	○ Don't know
Lisbeth	● Yes	○ No	○ Don't know
Cathrine	● Yes	○ No	○ Don't know

Topic related messages:

05/02/2004 12.32.30	**Paula**	let's finish quater 2
05/02/2004 12.32.13	**Paula**	lisa, and you?
05/02/2004 12.31.59	**Paula**	ok. deal? 9 24 32 and 54
05/02/2004 12.31.32	**Cathrine**	yes, i say i thinks so i agree
		come on, do you agree we do some market research? it is necessary and not

Figure 3-10. The voting tool.

3.1.4 Summary: Importance of the game indicators for collaborative playing

The model of the playing paradigm is presented in Figure 3-11. This figure illustrates the fundamental structure of playing the game. This requires players to find information, process the information, make decisions collaboratively, and consider information when cooperating with other team members to select appropriate interventions. Under the condition of geographically dispersed team members, the interaction process is through CMC (general and specific chat). This process requires them to exchange their existing mental models toward the problem being solved, learn the consequences of their decisions, and gradually learn new ways of thinking and skills in solving KM problems in an organisation trough mediated communication – text-based chatting. Consequently, the characteristics of playing and communicating are not only complex but also uncertain and equivocal, and thus close to the real world situation.

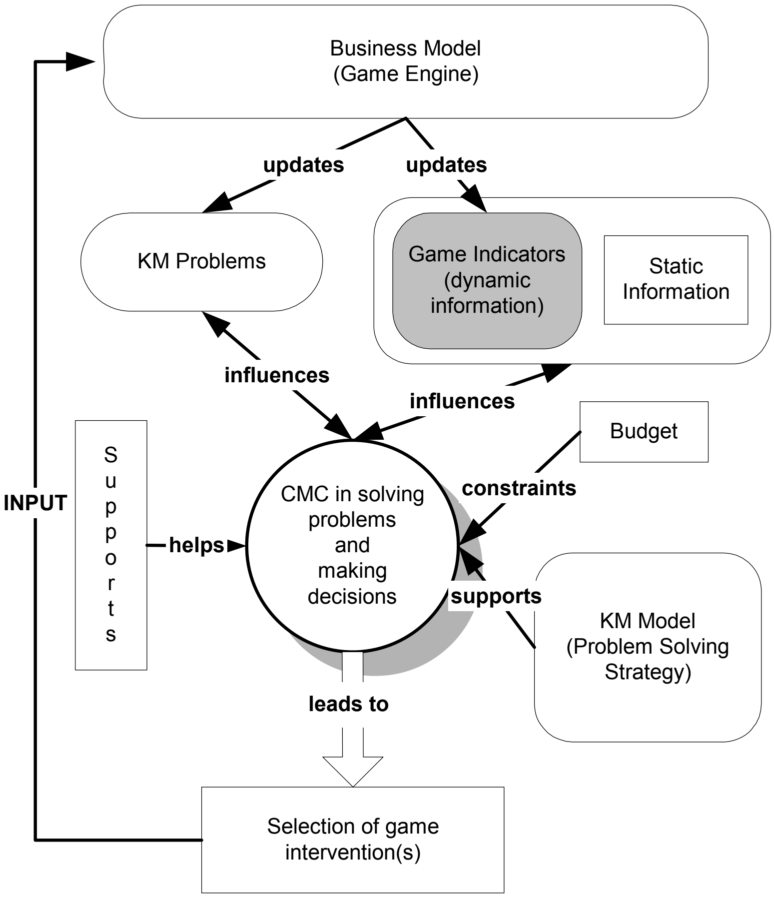


Figure 3-11. Basic structure of players' interactions in the KM Quest.

The complexity and density of numerical indicators of the BM that represents the status of the company (Coltec), potentially can create confusion about how to interpret and understand the indicators. This adds to the equivocality of tasks in the collaborative problem solving process. Additionally, the complexity is not only located in the number or variations of the characteristics of the game indicators, but also in the limitations of the medium which contributes to communication difficulties during interaction requiring knowledge exchanges. Having a non-visual communication tool for mediating the collaborative problem solving interaction, creates a situation that is advantageous for learning and working purposes (textual presentation and reference, cost-effective, and spontaneous) but disadvantageous for communicating and thinking (no visual proximity, risk of being in a non-conventional decision process, less comprehension, and limited information and knowledge exchange).

According to our theoretical perspective, the major concern is the process of making sense of the problem being solved and the integration of supportive information/data from the business variables to achieve meaningful interventions in collaborative communication processes. In Figure 3-11, we can see that the process of CMC (text-based chatting) in collaborative problem-solving and decision-making, is directly influenced by players' understanding of the KM problems and the values of the game indicators.

We think that the need for implementing visualisation to create meaningful support for the decision making process and for enhancing learning in a restricted CMC condition, has become evident by briefly sketching the playing process in KM Quest. To have meaningful visualisations we have to consider that the most unique element of playing sessions is the way KM Quest simulates situations, processes, and provides information that commonly can be found in a real organisation. The elements of reality and situatedness of the organisation pictured by the game, provide the most compelling consideration to visualise the game indicators.

In the next section the needed visualisation strategies to display the 82 game indicators are described.

3.2 Visualising the game indicators in KM Quest

The previous section emphasised the importance of the visualisation in the playing process of KM Quest. In this section, we will elaborate our strategy to achieve the implementation of the visual artefacts. It is assumed that the effort to visualise the game indicators in KM Quest should not be similar to just visualising indicators as in other computerised games. We share the belief that visualising game indicators is highly related to positive motivational effects for playing, but having a meaningful visualisation of game indicators in KM Quest to support collaborative communication is a much more important goal to achieve.

In the next sub-sections, we first define the main principle behind providing a "transparent" structure of the Business Model (BM) in visualising the indicators. The section continues to elaborate two visualisation considerations: general and specific. The general considerations are believed to deal directly with the equivocality (see Section 2.2.3) of the tasks in group decision making under limited communication modalities, particularly in tasks that are characterised as knowledge intensive activities. It is expected that visualising the indicators will reduce the probability of conflicting interpretations of information taken from the game in the communication process and will challenge the participants to arrive at one shared meaning of the information. To achieve these goals, visualisations as artefacts must be recognised by the viewers and be relatively easy to comprehend. Comprehending visualisation artefacts usually requires individual cognitive efforts. The specific considerations of visualisation will deal with reducing cognitive effort in comprehending the visual artefacts.

3.2.1 The principle of visualising business indicators

Two considerations that are believed to support the playing process, are adopted to define the basic principles of information visualisation in KM Quest.

The first consideration is the character of the interaction between players and the game system and between players themselves to deal with the complexity of actions and thinking, in particular when carried out collaboratively. This interaction is comparable with the situation where a team of managers together has to deal with KM problems and the complexity of organisational information.

The second consideration is the complexity of the BM of KM Quest, which is intentionally designed analogically with the complexity of the nature of business and economic systems in general, in which we can find heterogeneity, non-linear relationships, synergy, irreversibility, loops, rapid changes, and so forth. This structure often makes decision making and problem solving in business and economic domains troublesome (Isaacs & Senge, 1992). In the previous section, it was also described that most of the variables of the BM are invisible to the players. Even though the behaviour of the BM is not directly exposed to the players and is not targeted as the main learning goal, there is some conceptual understanding needed about KM that is related with the BM (see Section 3.1.1):

- How to translate business indicators and KM indicators into KM bottlenecks;
- What is the relationship between KM bottlenecks and KM actions;
- What is the effect of the implementation on business and KM indicators;
- KM actions often have delayed effects.

The points above suggest that by providing information about the company the indicators are functional to support the acquisition of learning a KM problem solving strategy. This again emphasises how important it is to represent the indicators meaningfully to support the interaction between the players and system in the playing process.

Machuca (2000) said that the most critical aspect of building a model of a social system in games is to find the feedback structure that dominates human decision making within the system. If the system does not allow the user to look for the causes behind the effects of their decisions, then users will operate by trial and error as in traditional black-box games, often making decision based on symptoms and losing the link between observed behaviour and underlying causal mechanisms.

We find that the above statements are ideal starting points for thinking about the transparency of KM Quest's BM when visualising the game indicators. It is expected that by giving transparency of the BM through visualisation, the playing process will improve, a better process to achieve understanding of the problem being solved and a meaningful information exchange in collaborative interaction can be realised. Thus, by visualising the indicators the conceptual understanding about KM and practising a generic KM problem-solving strategy can be achieved through meaningful collaboration - finding common ground and analysing and inferring the problem being solved using data from the BM- can be achieved in a seamless way.

The transparency that we try to achieve in the visualisation is closely related to the collaborative playing process in the sense of supporting: (1) communication tasks between players; and (2) the needs of knowledge intensive tasks –

understanding a large amount of data, sense making of unstructured data, pattern recognition, and data-knowledge extraction. In addition, the transparency may also provide clues and links about crucial characteristics of the case description, such as the complexity of the interrelation between the business indicators and their individual characteristics and the unique characteristics of knowledge in organisations: volatile, embodied in agents with wills, wide ranging impact, and so forth (see Section 2.1.1).

Communication theories define visual representations as a part of conversations of people. People commonly include visual representations to explain their ideas. Based on this premise, our opinion is that people share the interpretation of symbols in their language that is closely related with the visual representations in their surroundings. The process of comprehending visual representations consists of looking at the agreement about the meaning they attach to the representation. Conventions of meaning and understanding from visual representations can be understood similarly as the acquisition of meaning in language exchange in general. In this sense, we think that visualisation provides “a common language” that could unify disparate perspectives and even merge different interests into common objectives (Asakawa & Gilbert, 2003). We consider there are two important factors implied by the previous statement: ease of embedding visual representations *in* the communication process or discourse and ease of comprehending the visual representation *through* the communication process or discourse. These two factors will lead to a better understanding in collaborative communication processes.

Looking at the characteristics of numerical information generated by the BM, the visualisation should purposively be made to translate this type of numerical information into a recognisable visual representation. One of the reasons to justify the last statement is that numerical information generally consists of very arbitrary symbols which are hard to learn, easy to forget, and are often embedded in culture and applications (Ware, 2000). However, we think that this arbitrary nature of numerical symbols should not lead us to neglect them in visualisation because numerical information is defined in a formal way (for example, with mathematical conventions), can aid in thinking, and is capable to inform about rapid changes. This suggests that in visualising numerical information, transformation of numeric information into representations that are acceptable and recognisable by the visual sensory system is required, but on the other hand they should still conserve the arbitrary characteristics of numerical information. This is also required by the analytical cognitive processes in solving problems.

In the process of collaboration in group decision making and problem solving, the process of finding relevant information, comprehending it, and relating it to the problem being solved must be done collaboratively. Likewise these processes will be found during the process of collaborative playing of KM Quest. We intend that our visualisation representation will contribute to: finding relevant information, comprehending it, and enable relating it to the KM problem being solved. However, as mentioned in the previous section, the text-based chat system used in the game has serious limitations for conveying complex information during equivocal tasks. The main characteristic of the verbal-textual information exchange is that it is simple and straightforward. Hence, the interpretation of simple messages often leads to a different understanding about the topics or intentions being communicated. The strategy to deal with the limitations of the communication channel is to compensate the individual cognitive process with the appropriate visualisations. We expect this can meet the requirements of collaborative communication tasks dealing with information processing in the following way: first, we expect visualisation to provide better support for individual cognitive processes to comprehend relevant information and relate the information to the problem being solved prior to the limited communication process; second, we expect better visualisation will also mean a better information finding process. When achieving these two goals, communication under limited modalities will not be too troublesome anymore and can lead to effective collaborative communication.

In the following sections, two considerations concerning visual designs are described. The first consideration deals with the main function of visualisation as part of the conversation in collaborative communication processes. It is expected that difficulties of communication during group decision making caused by the need to find information, will be reduced by this design principle by means of giving structural information of objects being discussed. The second consideration deals with the specific function of understanding and comprehending the visual representation through the communication cognitively. This specific structure of the visual design is meant to support cognitive processes when dealing with specific tasks, hence a reduction of the cognitive load in analysing and integrating information from the game indicators for solving problems in the game.

3.2.2 General considerations of visualisation

This section first presents the underlying principle and goal of the general visual design. The principles of the information visualisation, such as consideration of the location and the complexity of the data from the indicators, are elaborated to shape actual design artefacts. In the following part some design solutions are described, such as considering grouping the indicators, selecting and combining types of relevant visualisation artefacts, and layout.

3.2.2.1 The principle and goal

As mentioned before, the general considerations in designing the visualisation of the game indicator refer to the text-based CMC process in playing KM Quest together. Generally, it is important that words be associated with appropriated images. Associating words with images is believed to create positive effects on sense making. The link between these two types of information can be either static, as in the case of texts and diagrams, or dynamic, as in the case of animations and spoken words (Ware, 2000). The first link is relevant for our visual design principles. There are two main factors that imply this link: maintaining static links and *deixis*.

- While maintaining the links of text and static diagrams, the Gestalt principles - proximity, continuity/connectedness, common region, and common region combined with connectedness, apply;
- When people engage in a conversation, they sometimes point or indicate the subject of a sentence by pointing with a finger or by glancing, or with a nod

> of the head. This gesture that links the subject of a spoken sentence with a visual reference is known as a *deitic* gesture, or simply *deixis*.

Correspondingly, in the playing situation of KM Quest, the communication process occurs in two ways: between players and the system and also among players themselves. Thus, the above points already predict that the process of communication between players and other players, and interactions of players with the game system require the presence of the above two factors.

It is expected that the playing and learning processes involve tasks to find relevant information, link the information with the problem, understanding the feedback from the past decision, and so forth. Collaborative communication between players in the form of verbal-textual conversations is expected to involve the following tasks: referring, pointing, comprehending, exchanging interpretation of the game indicators, and relating the game indicators to other information from the system. All of these generate the need to specify where and what is the object being discussed in the course of a conversation. This need suggest that the location of the visual objects and characteristic of information being visualised are two important considerations. Below these two considerations are described.

Location of visual objects

The location of the visual objects is the first important consideration. It is basically related to visual references of the object being discussed in action-oriented conversations. Particularly in the case of text-based communication, the visual reference about the object being talked about has to become the first anchor of sense making in a conversation. Thus, in the perspective of the user, the location is obviously a very important point in communication processes. But beside that, in the perspective of the designing visualisation, the location of visual objects determines the type of information that might be needed in the communication process.

In the KM Quest environment, there are 3 main locations where visualisation might be needed: (1) Main interface; (2) KM model; and (3) Additional charts and diagrams.

In the main interface, a universal and simple display is needed to illustrate general game conditions. There is very limited space in the interface (see Figure 3-9); consequently the amount of information presented in this location must be limited. However, the information is very important and must be attractive to maintain interest in the playing process. In this interface we only show the current value and the relative changes (increase, no change, decrease) of the main business indicators.

While playing, and learning applying the KM model, players might need detailed numerical information about business indicators to support tasks in the sub-tasks of the KM model. They might need a simple display which contains dense, discrete, and detailed numerical information. Numerical tables could meet these requirements. However, well-designed tables are required to effectively illustrate the situation of the business (model) and provide links to the sub-tasks in the KM model. For instance, one sub-task of the “Focus phase” in the KM model is to find a complete overview about the actual states of the business process of the organisation (see Figure 3-4).

The additional charts and diagrams are the special modules designed to support the whole playing process. The goal of implementing the separate charts and diagrams is to provide more comprehensive information from the BM. The emphasis on the visualisation is to provide spatial and qualitative numerical information about the game indicators that is not present in other two locations due to the need to prevent a cluttered interface.

The characteristics of the location determine the function of the visualisation needed and also characterises the type of information needed. This provisionally points to the type of visual information needed in each location.

Complexity of the set of indicators: characteristics of numerical information

The complexity of the set of indicators is the second most important consideration in designing visual information. It is directly related to the characteristics of the data being visualised and its purpose to visualise particular numerical information. In considering this factor, it is commonly accepted that differences in measurement units are crucial.

The game indicators of KM Quest reflect the status of the BM. The total number of game indicators, as explained in the previous section, is 82. The indicators can be categorised into two main layers: business related indicators and knowledge related indicators. They are represented by various measurement units.

In the business related indicators, there are many variations in measurement units such as: levels, indexes, percentage (proportion), time-related indicators and numbers. Time and levels are peculiar concepts, as they cannot reach maximum values. Moreover they are relative to their own history as will be explained below. An experienced player might know that a time of four months is not bad at all, but an inexperienced player might just as well think that it is very long. Understanding of levels and times has neither a common qualitative meaning among players nor an individual understanding.

The indicators that should be displayed in the knowledge domains are divided into groups: Knowledge Gaining, Knowledge Development, Knowledge Transfer, Knowledge Utilisation, and Knowledge Retention. Each group has 3 sub-indicators: Speed, Effectiveness, and Efficiency. There is an exception for the knowledge retention variable, which only has the effectiveness indicator. These indicators have indexed values: a value which is equal to 1 reflects a very low performance on this indicator, a value 10 reflects an excellent performance on this indicator.

Obviously, each indicator has its own measurement unit which can be categorised into several types. The useful way of considering the types of data is the taxonomy of number scales. Stevens (1946) categorised 4 levels of measurement: nominal, ordinal, interval, and ratio scales. This also applies similarly to the BM variables of KM Quest. For instance, the knowledge related indicators use indexed or ordinal values from 1 to 10. The business indicators are mostly interval or ratio type data. The interval values have a limited range of numbers, but the units can be large or small. The ratio values can be very small to very large without boundaries. For example: the profit of Coltec starts from 10 million euro but can increase to any number.

The different measurement units and levels lead to a design strategy for grouping and sequencing the indicators, selection of type of charts and diagrams, and designing the canvas. In principle it is quite confusing to compare variables which have a different measurement unit and level, for instance, in combining ordinal and interval values in a single display to compare values over time.

3.2.2.2 Grouping the indicators

The purpose of grouping of indicators is to create meaningful clusters and simplify the understanding of data being presented. Since there are 82 game indicators, the grouping of indicators is also pragmatically meant to compact information representation in the web pages of the game system.

We think that grouping the indicators is considered as the most important design strategy because almost all of the following visualisation design strategies were based on this consideration. The ultimate goal for grouping and clustering the indicators is to try to create the contextual meaning of the data in order to enhance the leveraging of the knowledge through the extraction and interpretation of data in collaborative playing (Rao & Sprague, 1998). Thomsen (2000) stated that general facts or assertions with high inference support, seem to function in the context of decision-making as what is typically called knowledge. However, the degree of generality is neither a necessary nor a sufficient condition for considering a piece of information as knowledge. He suggests that data and knowledge must be functional to the decision-making process. This means that grouping and sequencing of the game indicators is a necessary condition to stimulate both general and specific (visual) inference processes, but should be followed by attaching the group of indicators to meaningful visual references that are related to the characteristics of the decision making and problem solving process. This suggestion reminds us that some of the indicators, if presented in a group, may lead to comparisons because one or more indicators may have inter-relationships. For instance, the number of employees in the marketing knowledge domain is directly related to the total number of employees in Coltec.

The relationships between indicators that were based on the clustering of the BM (see Figure 3-5) were the main consideration in making the groups of indicators. Within each cluster, the indicators are grouped into smaller chunks, based on similarities of measurement units and level. These processes result in groupings of indicators in four main BM categories: organisational effectiveness variables, business process related variables, knowledge related variables and knowledge processes related variables (see Table 3-2).

Table 3-2. Results of grouping the indicators: visualisation packages.

Category	(N) Packages
Organisational effectiveness indicators	8
Business processes related indicators	12
Knowledge related indicators	3
Knowledge processes related indicators	9
Knowledge Map	1
TOTAL	33

This clustering resulted in so-called "indicator packages". These groups of indicators are visualised in the charts and also in the numerical table.

These clusters will also influence our visualisation strategy that is related with the selection of type and combination of charts. This strategy will be described in the next sub-section.

3.2.2.3 Determining the type of visual objects

There are several types of visualisation commonly used in representing business information and in learning materials: Charts, Numerical tables, and Diagrams. In Chapter 2, it is also mentioned that these types of visualisation, will support group decision making and problem solving processes. We expect that these types of visualisations will support the playing process in KM Quest. Below we discuss the theoretical consideration for each type of visualisation.

Numerical tables

Senn (1995) stated that the use of both manual and electronic spreadsheets or numerical tables in presenting business information in organisations is to record much numerical information, summarise raw data and produce information for the analysis of organisational performance, improve organisational planning, simplify control processes, improve communication and motivation, and help managers to make decisions. This is not too surprising, because a numerical table can convey very detailed and differing numerical information. Use of numerical tables is commonly found in scientific reports that give quantitative information to the readers. One of the drawbacks in using numerical tables is they are too detailed and less effective in giving qualitative and spatial information about the data (see also Section 2.4.1).

Nonetheless, we think that numerical tables can be helpful to provide detailed and comprehensive information about the game indicators, particularly when players need to learn how to use the KM model (see Figure 3-4). The main purpose is to organise the game indicators into spreadsheet tables to provide support to understand the KM model and the conceptual knowledge that is related with the BM as well.

Acknowledging the weaknesses of the numerical tables to display more spatial and qualitative data, there is not much visual design for them to do. The first attempt to reduce the difficulties to understand a large numerical table is to organise the categories of the data being presented and reduce the complexity of the values.

The detailed strategy to improve the understanding a numerical table is described in Section 3.2.2.4.

Charts

In general according to instructional design theories, graphic applications are classified as cosmetic, motivational, attention gaining, and presentation artefacts in learning (Ware, 2000; Wileman, 1993). A chart is also very common in scientific visualisation. As a form of graphical information, a chart is characterised by the organisation of data information on a page by plotting groups or categories of data into x- and y-axis. There are different well-known types of characteristics and forms, for example the two-dimensional line, bar, and scatter diagrams. Each of them contains potential meaning besides only showing data. According to Wileman (1993) there are several type of charts and its own characteristics. Below we described some of them that will be used in our design strategy.

A Circle or Pie chart is an appropriate format to use when the numerical data are to be stated as percentages of a total or a whole. A Circle chart is always divided into segments. Simple line pattern, tones of grey, or colours can be applied to these individual segments to create visual contrast. This highlights the relationships; it also compares each segment to the whole. If necessary, more than one circle can be used in visualisation. It is also possible to incorporate two aspects: percentages and proportional increase of size of the total number over time.

A Line chart is a useful technique for displaying the overall movement of numerical data over a period of time. This format can be used to present a large amount of data in a single display. This format can also easily display highs and lows, rapid or slow changes, or the relative stability of values. In addition, the Line chart is an excellent format to use when you need to show comparisons and relationships. It can also incorporate two, three, four or more scales to compare the same item in different time periods.

A Bar chart is one of the most convenient and widely used formats for displaying numerical data. The length of a bar corresponds to a value or amount. When a second group of bars or columns is added, it is possible to compare data. As more bars are added, more comparisons are possible. There is a distinction between a Horizontal Bar chart and a Vertical Bar chart. The horizontal one usually deals with different items compared during the same period of time. This type of chart is arranged so that items compared are listed on the vertical axis and the quality or amount scale is on the horizontal axis. The vertical bar chart usually deals with similar items compared at different periods of time. The vertical bar chart lists the amount scale on the vertical axis and time or item on the horizontal axis. Bars can overlap each other to emphasize groups; one can also use texture or colour to highlight distinctions. Other types of Bar charts are the Stacked-Bar charts. The most important differences between two types of bar charts are that the surface of the bars can be coloured to give extra visual clues and secondly, the option to stack bars to display ratios.

Selecting and combining types of charts

Selecting a type of chart is related to measurement units and levels of the values that will be displayed and also characteristics of the type of charts. For instance, in displaying levels and time-related indicators (see page 67), the concept of time is intuitively associated with a horizontal position and therefore horizontal bar charts seem to provide a nice possibility to visualise this indicator. In displaying the indicator of levels, the qualitative concept of 'height' comes to mind almost immediately. Level type indicators all have a clear qualitative attribute: high levels are good and low levels are bad.

Bar charts are very suitable to display height and length. However, principally, we can not attach all dimensions to columns in a bar chart to display different data values and information categories, for instance, different bar length to display the length of time or the highness of level and different bar width to display the category of the value. Ware (2000) said that using graphic size (as common in a bar chart) to display the category of value is likely to be misleading, because we tend to interpret size as representing quantity of data which is not available in the category. For example, using different bar width to display nominal information is misleading.

Some chart design strategies say that there are possibilities to combine more than two types of charts in one visual display. The combination of primary and secondary, or even tertiary charts is believed to enrich the message being displayed, giving added value, and overcome weaknesses of a specific type of charts. In the case of displaying fluctuation of levels over time, a bar chart has its limitation to evoke a continuous representation of values over time, because usually the distance between the columns disturbs the learner's perception of the trend in the fluctuation of continuous values (height of columns). Unlike a bar chart, a line chart has better characteristics for supporting trends or detecting trends in continuous values. The advantages of a Line chart are to stimulate understanding of data from interpolations the lines when the time scale is not regular and the better readability of trends. The same things may be applied to stacked bar charts which display ratios of values. We can attach two or more lines in a stacked bar chart to display the ratio of fluctuations. That is why in several designs of charts we added the line chart as the secondary chart in order to improve the learner's understanding about the level type indicators (for example see Figure 4-3 and Figure 4-8).

Schematic Map: a special feature

The original schematic map is a visualisation that depicts mapping of important hierarchical elements of a domain into a specific (geometric) surface, locations, or position in a diagram. This concept uses some important properties of the earthly environment that consist of objects with well-defined surfaces, surface textures, surface colours, and a variety of shapes (Ware, 2000).

The idea of a map is not originally designed for the purpose of the KM Quest system. This kind of technique is originally called tree-maps and is applied to visualise tree-structures of a large data storage system such as a hard disk and other back-up apparatus (Shneiderman, 1992). However in its further development the tree-maps have been applied to support analytical hierarchy processes to improve decision making. This visualisation strategy is believed to be very efficient to display impacts of decisions, speeds up exploration and provides better understanding of the relative impact of other component criteria (Asahi, Turo, & Shneiderman, 1995). The most recent application of tree-maps is to display stock-exchange fluctuations (see http://www.smartmoney.com/marketmap). The idea is to have a marketing map of stock exchange transactions; it can show the volume of stock exchange trade and also the variation of values over time. For our purposes, the knowledge indicators will be transferred into a "Knowledge Map" (K_Map).

Analogous to the tree-maps, our schematic map (Knowledge Map) is believed to be very powerful to support KM decision making because of its ability to cover the mapping of a large set of values about knowledge indicators in each domain into a single and straightforward schematic display. An instant but global overview of a large amount of data is the benefit of this visual object.

The mapping diagram has the properties of surface filling, location, position, and size. Each of these properties is taken into consideration in visualising the knowledge processes indicators which will be elaborated in p.75 and p.81

3.2.2.4 Canvas design: Determining a consistent layout

The strategy to design all types of visualisation is based on generic aspects: efficiently use the game space, easy to be implemented, flexible, consistent, and meaningful. The last aspect plays a very important role during the design phase. Meaningful visualisation might be achieved if the message behind displaying indicators is received consistently. For this reason there is a very strong need to have a consistent canvas design. There are several criteria that are used in determining the design of canvas: efficient size of objects, locations, and the used of available space in the web pages.

Below is the canvas design of 4 types of visual objects used in the system.

Canvas design for displaying the main business indicators in the user interface

Figure 3-12 depicts the general layout of displaying the 3 main business indicators in the user interface (see number 2 in Figure 3-9). The type of icon is connected with the type of indicator annotated. In Section 3.2.3.3, this will be elaborated (see Figure 3-21, Figure 3-22, Figure 3-23, and Figure 3-27). The main principle is to change the display of icons, values, and arrows dynamically.

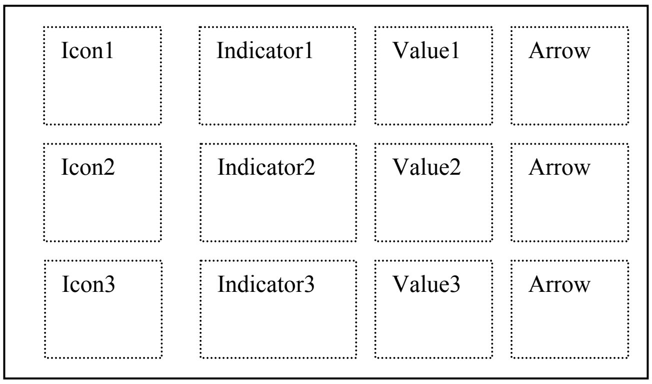


Figure 3-12. Layout specification of visualisation of main business indicators.

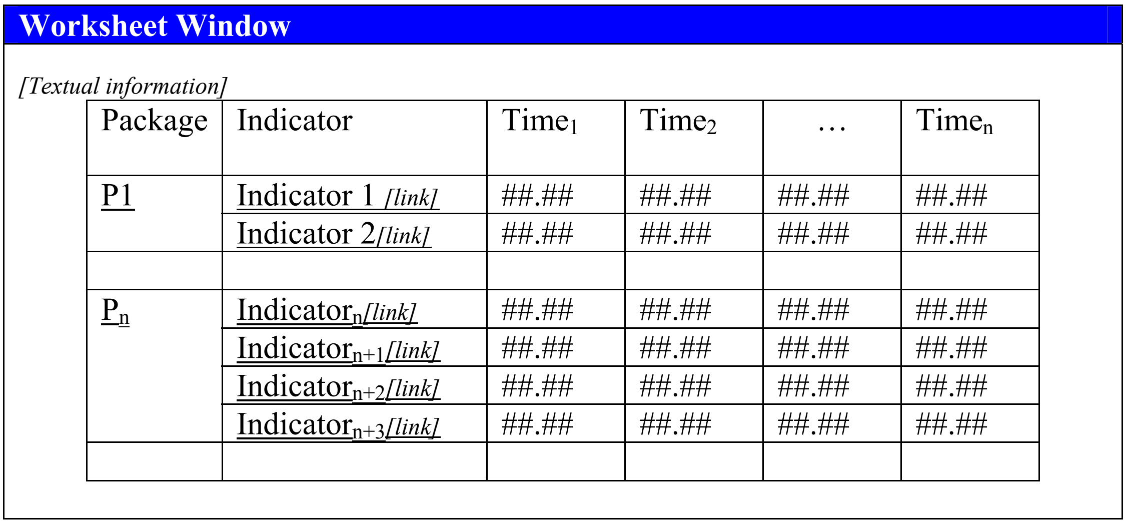
Canvas design for the numerical table

Ehrenberg (1981) suggests a few simple rules to increase the communication power of a table of numbers:

1. Giving marginal averages to provide a visual focus;
2. Ordering the rows or columns of the table by marginal averages or some other measure of size (keeping to the same order if there are many similar tables);
3. Putting figures to be compared into columns rather than rows
4. Rounding to two effective digits;
5. Using layout to guide the eye and facilitate comparison; and
6. Giving brief verbal summaries to lead the reader to the main patterns and exceptions.

Not all of these points can be fully applied to our design of the numerical table. Points 2, 3, and 4, are the major considerations in displaying the numerical information in our table design. Point 1 and 5 are limited applied to the design because of limitation of the size of the web page and the large numbers of game indicators that should be displayed. Point 6 was not applied to the design because extended explanation of each game indicator and its measurement unit is available in the indicator book (see number 6 in Figure 3-9). We linked each of name of the game indicators to the corresponding section in the book.

Figure 3-13 depicts the general layout of the numerical table. All visualisation packages and indicators are linked to the book about visualisation (see Figure 3-9). We believe this layout will increase readability and comprehension of the numerical information. One important factor of comprehending the numerical information is to compare the development of the data over time. Hence, supporting the interpretation of differences over a long period of time as trends.



Worksheet Window

[Textual information]

Package	Indicator	Time$_1$	Time$_2$	…	Time$_n$
P1	Indicator 1 *[link]*	##.##	##.##	##.##	##.##
	Indicator 2*[link]*	##.##	##.##	##.##	##.##
P$_n$	Indicator$_n$*[link]*	##.##	##.##	##.##	##.##
	Indicator$_{n+1}$*[link]*	##.##	##.##	##.##	##.##
	Indicator$_{n+2}$*[link]*	##.##	##.##	##.##	##.##
	Indicator$_{n+3}$*[link]*	##.##	##.##	##.##	##.##

Figure 3-13. An example of general layout of the numerical table.

In KM Quest, the numerical tables will be attached directly to the worksheets in the KM model. All tables will follow this layout.

Canvas design for the charts

Using the same "style" throughout will make it easier for learners to understand the different charts by eliminating the need to process different layout styles first. The styles are also generated by considering the theoretical framework of chart comprehension (Carswell, 1992; Shah & Carpenter, 1995; Trafton & Trickett, 2002) that offers two types of default layout for displaying charts. The standard properties of these figures consist of: a background, a title, x- and y- axis with their own label and data type and range, type of chart(s), legend, and additional statistical facilities.

Several combinations of visual properties in charts are possible: iconic annotation, trend and a value that shows the difference between past and present values of indicators. The primary chart may consist of the combination of one or more chart types: line, bar (vertical and horizontal), stacked bar, clustered bar (see Figure 3-14).

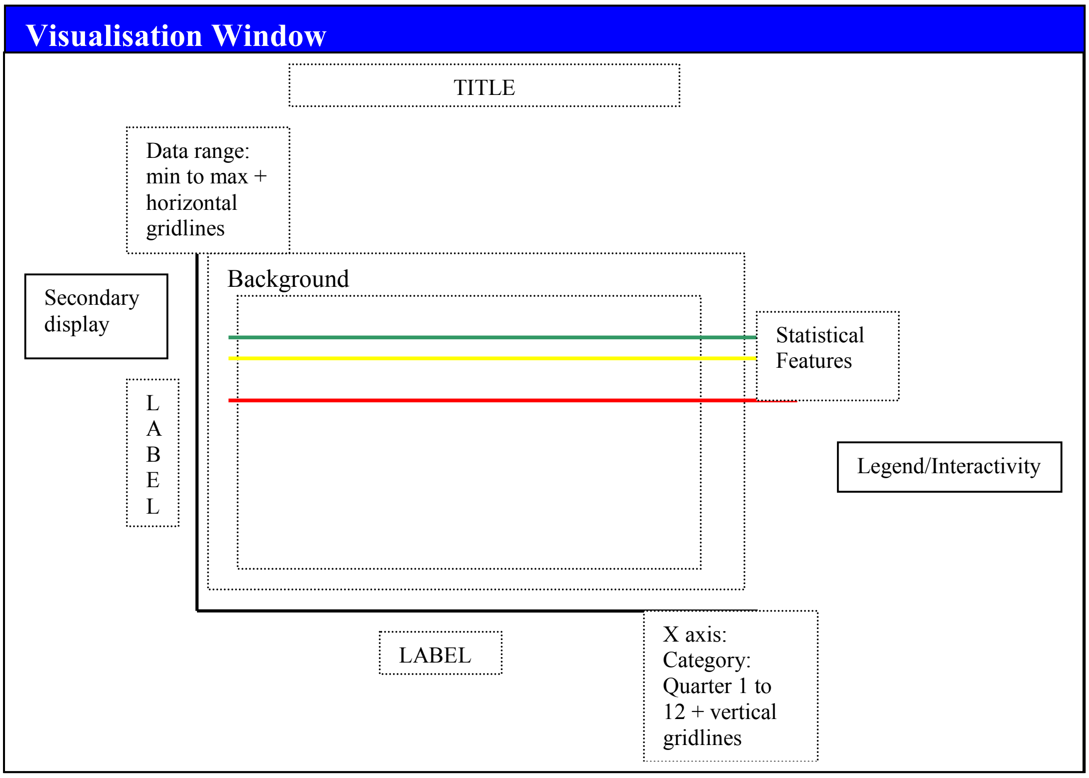


Figure 3-14. General layout of the chart canvas.

Canvas design for the mapping- diagram (K_Map).

The basic form of K_Map is a two-dimensional surface. This surface reflects the unity of the three knowledge domains. One square means one knowledge domain that has 5 knowledge process properties: (1) gaining, (2) development, (3) retention, (4) utilisation, (5) transfer (see Figure 3-15).

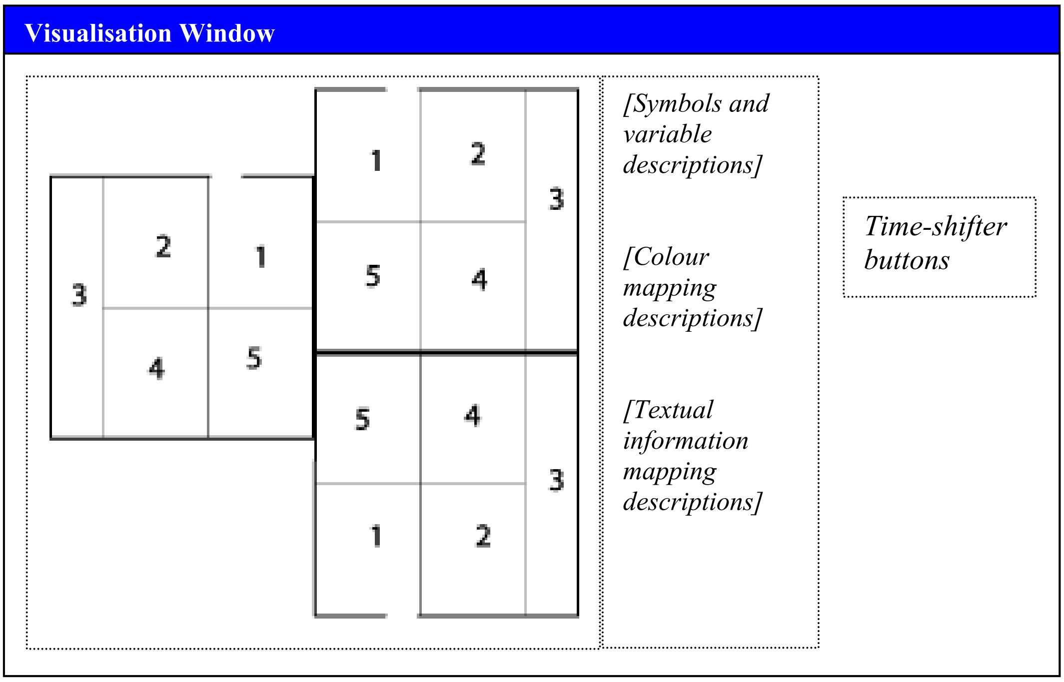


Figure 3-15. The canvas design of the Knowledge Map.

The reason why the surface is divided into 3 identical squares which is divided into 5 same-size sections is to emphasise that each knowledge domain is equal. Position, size, and section of each square are always fixed. The changes of the values of the properties of every knowledge processes variable are represented by the changes of the filling colour inside each section of the squares. We could also say that the change of the value of each variable is mapped to a pattern of colour changing. By this dynamic colour changing, we expect that players can detect immediately the changes of the values in each section. As a section can only have one colour at the same time, it was decided to visualise the effectiveness property of knowledge process variables in the colour mapping only. This will be explained in section 3.2.3.2.

Besides the basic form of the K_Map, we have to include other information to enhance the visual understanding of the variables by adding textual information. Two types of textual information are included in this design: dynamic and static. The property of speed of knowledge process indicators is visualised by dynamic textual information in each division. To support the understanding of the meaning of the location of K_Map and its symbols, a section that provides static textual information is also presented in the canvas.

Colour is used to mark that a value has changed. A problem is that the learner may not remember that the previous value has changed into a new value after knowledge management interventions were submitted. An additional facility is needed to show the difference of past and current colour. For this purpose, a functionality that can show the history of the value over time is implemented in the K_Map. We called this functionality as the “time-shifter” button (see on the right part of Figure 3-15). By pressing this button the player can see colours from previous time slices. The player can change the time frame, from the first quarter until the current one.

In the above sub-sections, the general design considerations of visualisation of the game indicators have been explained. In order to complete the overall design, there are some specific considerations that need to be elaborated. In the next section, all specific considerations that intend to support the comprehension process of visual objects will be described.

3.2.3 Specific considerations

Even though the numerical table is classified as a part of the visualisation strategy, its ability to display visual information is very limited. We think that the comprehension of numerical information from numerical tables is a straightforward process: extracting symbolic and discrete data (Meyer, 2000) to support a particular analysis process (for example, in performing the steps in the KM model). It is assumed that comprehending discrete and arbitrary data is only dependent on a low level of perception, which is conventional and symbolic. It requires a learning process to understand the perceived symbol and has a very limited perceptual basis (Ware, 2000). We do not think that comprehending numerical information requires more specific design considerations than those that have been defined by Ehrenberg (1981) on page 73.

The specific design considerations described in this section are thus mainly to support cognitive processes in comprehending the visualisation of the game indicators by charts and the knowledge map. It is highly connected with the cognitive-analytical process of comprehending the visualisation representation and its relationships with its components, and relating the comprehension of visualisation to other visual representations and to the problem being solved.

3.2.3.1 The principle and goal

Most of the design principles aim to support players in understanding playing and in learning specific tasks that require comprehending detailed information from the BM, such as thinking and problem solving tasks, memorising, and comparing information cognitively.

Graphic chart displays are considered to present spatial information that is required to make associations between values or perceiving relations in the data which can be referred to as *spatial* tasks, for example: comparison between data points or recognition of trends (Meyer, 2000). Cleveland (1994) recognises three types of operation of perception to extract patterns of information from graphics: (1) symbol detection, (2) assembly or grouping, and (3) estimation (discrimination, ranking, and rationing). Other scholars stated that extracting information from graphical representations can be done by simply reading off the information under the condition that the information is explicit. Creating visual imagery (for example in forecasting, extra- and interpolating) is needed in the condition that information is implicit (Trafton & Trickett, 2002).

Before we can understand how charts can support players to perform spatial tasks, we have to consider charts comprehension theories. There are, at least, three well-known theoretical models of the chart comprehension process. One is the theoretical model of graph comprehension defined by Bertin, in Trafton and Trickett (2002). According to this theoretical model, visualisation comprehension in reading charts consists of three tasks: (1) encoding visual elements of the display: identify line and axes; (2) translating the elements into patterns; and (3) mapping the patterns to the labels to interpret the specific relationship communicated by the chart, determining the value of data points.

The second theoretical model from Freedman and Shah (2002) applies the Construction-Integration (CI) Model of text and discourse comprehension as follows: *First*, during the construction phase, a reader activates visual information as well as a large set of prior knowledge associated with that graph. This is an automatic activation of perceptual features that guides processing of data. Types of graphs and other basic visual elements – title, background, measuring unit, textual information, colours, and legends are important elements in this first phase. *Second*, during the integration phase, disparate knowledge is combined into a coherent representation. When information is explicitly represented in a chart so that no inferences are required to form a coherent representation, less effort is required in this phase. However, when the reader must draw some inferences in order to form a coherent presentation or relate it to the task, then the integration process is effortful. In other words, if relevant information taken from the visual elements is easily linked to prior knowledge, this produces effortless comprehension. Consequently, the perceptual organisation of the data is a very important factor in designing charts, which will influence viewer's spontaneous interpretation and understanding of data, even when the data and tasks are relatively complex and the domains are unfamiliar. In addition, the way visual elements are grouped together in the total display is more important than the graph format (Shah, Mayer, & Hegarty, 1999).

The third theoretical model from McKenzie and Padilla (1986) defines the following objectives in interpreting (line)charts: selecting appropriate axes, locating points, drawing lines of best fit, extrapolating, describing relationships between variables, and interrelating data displayed on two graphs.

These three theoretical models of chart comprehension suggest how important the contribution of the elements and components that form charts are. The other issue mentioned by the CI model is the familiarity of the chart and its components with prior knowledge. Most of the properties of maps and diagram are utilised to achieve better comprehension of the charts and the schematic diagram (K_Map). Peculiarity and familiarity of the visual elements and components of graphical charts to support players to detect and create understanding of patterns of numerical information being visualised, is the foremost design principle presented. Supporting the process of detecting symbols and other information to understand the numerical information, comparing of numerical information, and predicting the tendency of the numerical information, are the goal of specific design consideration presented in this section. In the next sub-sections, the use of colour and other visual elements to ease players' understanding of the numerical information from the game indicators, is described.

3.2.3.2 Enhancing comparison of values with colours: consistency and qualitative values

The application of colour in information visualisation is commonly known not only as having aesthetic and artistic value, but also a functional one to display data. For example, some colour applications are used for labelling and sequencing – mostly for maps (Ware, 2000).

Filling colour and saturation representing consistency of data

To provide the learner with some consistency it would be handy to apply identical colour schemes to the business process related indicators and brightness of colour and particular data points for the knowledge related indicators. In this case colour is used to establish categories that enhance assembly of the data in a cluster and provide quantitative encoding that increases estimation efficiency (Cleveland, 1994). Distinct and unique hues are used in this technique.

To categorise business indicators, some colours are mapped pragmatically to the type of indicators being displayed. For instance a yellow bar is used to display the customer satisfaction index indicator and black-white one to display differences in the indicator of expenses. Most of the selection of displaying these indicators is based on pragmatic reasons: contrast with background, distinctness, and uniqueness of hues.

Other indicators that belong to the three knowledge domains use consistent colours as follow:

- *Marketing* = gradation of grey to black;
- *Production* = gradation light blue to dark blue;
- *R&D* = gradation light magenta to purple.

Correspondingly, the filling colour of the chart in the primary display, for example the colour of bars/columns, or lines is also mapped consistently to specific colour gradients for each domain. We believe that learners will remember the basic colour of the domains, so that they can recognise the domain colours in every visualisation directly and consistently.

Moreover, differences in colour brightness of different data point objects that are used to discriminate knowledge processes indicators (see Figure 3-20), are used to discriminate between knowledge processes properties indicators. Three levels of brightness of the data point objects' colour are used in each domain for the knowledge processes properties: (1) Efficiency of knowledge processes indicator = 100% bright; (2) Effectiveness of knowledge processes indicator = 70% bright; and (3) Speed of knowledge processes indicator = 30% bright.

Figure 3-16 shows the application of 100% brightness of black to categorise the data points of the efficiency of knowledge processes indicators in Coltec's marketing knowledge domain. Figure 3-17 shows the application of 30% brightness of black to categorise the data points of speed of knowledge processes for the same knowledge domain.

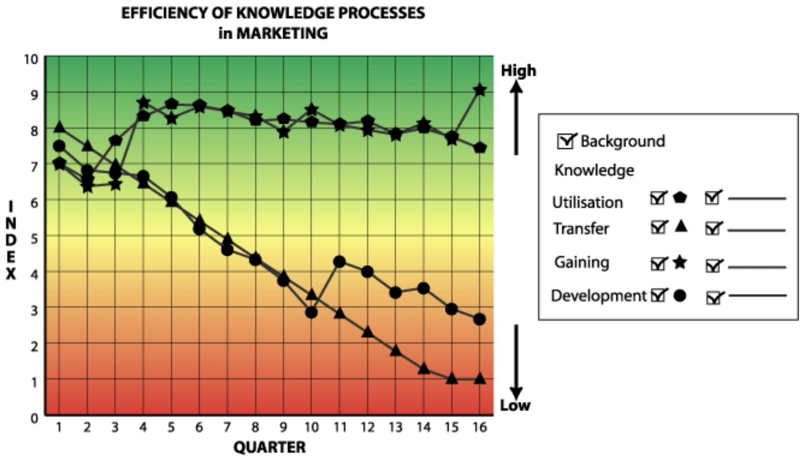


Figure 3-16. Efficiency of knowledge processes in marketing.

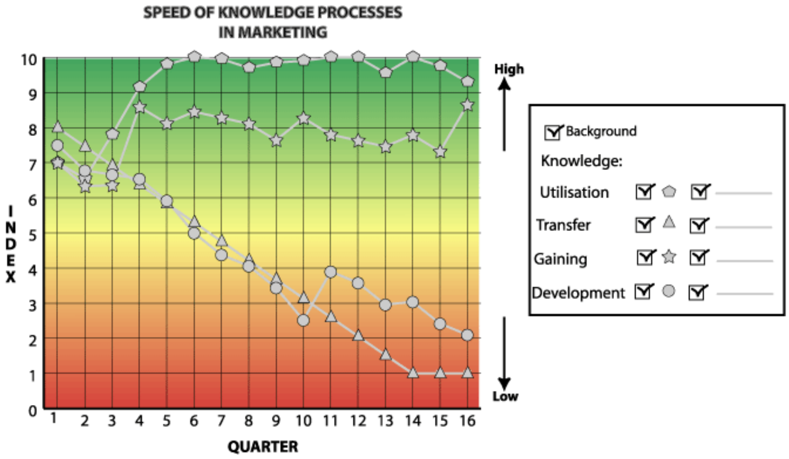


Figure 3-17. Speed of knowledge processes in marketing.

Colour representing qualitative values

For enhancing the symbolic meaning of indicator values, they are mapped to different colour patterns to represent the qualitative meaning of the data. The colour that we applied in this design is colour sequences or *pseudocoloring* which is the technique of representing continuous varying map values using a sequence of colours (Ware, 2000).

There are two possibilities to exploit the meaning of colour: background of charts and filling colours of the K_Map.

The background of charts can be used to display additional information. In our design we use colour gradations from red to yellow-to green, which is equivalent to the meaning of traffic lights, indicating “good” and “bad” values of indicators. To give a user extra clues about the meaning of the values, the use of colour can help in the interpretation of the graphs. This colour scheme is applied to the background of charts. If we take the bar chart as an example, this background colour will provide a secondary interpretation that the height of the bar against the coloured background has a meaning, like “continue this way” if green, and “watch out” if red. However, one should keep in mind that these conventions do not necessary hold across cultural borders (Ware, 2000).

Colour is used to fill all sections of a knowledge domain and its subsections in the K_Map (see Figure 3-18). It indicates values of the indicators, for this purpose colour is translated into a colour gradient as an indicator of values from 1 to 10 (minimum to maximum). This graded value is also supported by Healey (1996) who stated that only five to ten category codes can be rapidly perceived.

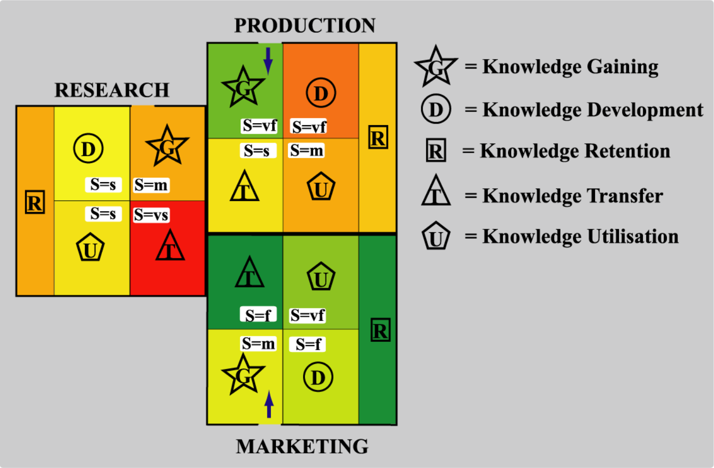


Figure 3-18. The knowledge map.

The colour gradient for Effectiveness is also based on the logic of red-yellow-green (traffic light). Intuitively, it will express the same meaning as a traffic light, so low effectiveness will be shown by red, medium by yellow, and green as high effectiveness.

Figure 3-19. The colour gradient for Effectiveness (from green to red).

3.2.3.3 Enhancing comparison of values with iconic annotations and smart legends

The problem with comparisons is not only consistency but also crowdedness of the data being perceived. In the case of a very dense data visualisation, a comparison is not only difficult but perceptually impossible to be made. The technique we first applied to enhance comparison uses smart legends and iconic annotations to attain a consistent form of data points by using specific shapes of icons. The second visual technique uses the qualitative meaning of the (un-)friendly nature in the expression of icons.

Smart legends: data point objects and their interactivity

According to Kosslyn (1994) a well designed chart should not display more than 3 variables at the same time, due to limitations of human perception in comprehending charts. When visualising more than 3 variables in one single display, it should be supported with interactivity features, which enable users to manipulate the number of variables displayed. For example, users want to hide one or more variable(s) in order to get exact data points or when several data points are too close to each other.

Next, different types of data point objects in the charts of knowledge related indicators are used (see Figure 3-20)

○ = Knowledge Development
⬠ = Knowledge Utilisation
□ = Knowledge Retention
☆ = Knowledge Gaining
△ = Knowledge Transfer

Figure 3-20. Different symbols for data points.

Looking at the properties of symbols for these data points, the outline of data point symbols always uses black, but the filling colour of the symbols follows the colour of the associated knowledge domain and the brightness value of its knowledge processes properties. These data points are connected with a line that has the colour of the corresponding knowledge domain. Implementation of data points in charts and the knowledge map can be seen in Figure 3-18 and Figure 3-16.

The checkboxes are used to hide or show the related information. For example, unmarking the 'Bar' checkbox will remove the bars from the chart and the line chart becomes the focus of visualisation (see Figure 3-16 and Figure 3-24).

Icons for the charts and the user interface

Icons do not only annotate the indicator by giving it a direct meaning, but also shows the qualitative meaning of values. These icons, presented in Figure 3-21 , are used to display the customer satisfaction index values from bad to good. These icons are used in the chart of the customer satisfaction indicator and also in the user interface (see Figure 3-9).

Figure 3-21. Changes of iconic annotation of satisfaction from 1 (left) to 10 (right).

Besides using iconic annotations of qualitative values, we also attached the meaning of the quantitative magnitude of data values to a gradation of the size of some iconic annotations that have a direct analogy with the measurement units of the data values. Figure 3-22 presents the changes of iconic annotation from a small to a large amount of money. Figure 3-23 shows the changes of proportions of data values by a 10% difference – these icons are used to visualise the changes of the market share indicator over time. These two types of icons are used in the user interface of the game to enhance the display of numerical information of the three main indicators: Market Share, Customer Satisfaction Index, and Profit (see Figure 3-9).

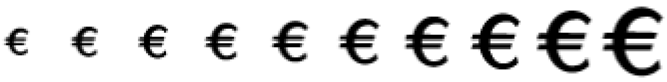


Figure 3-22. Changes of iconic annotation of currency related values.

Figure 3-23. Changes of market share values in the user interface.

3.2.3.4 Increasing awareness for numerical changes tendencies: statistical features

The statistical features are implemented in the charts to increase players' awareness about numerical changes tendencies, particularly after playing more than 5 quarters. We expect that players can obtain a predisposition of numerical changes over time easily. These features are drawn as horizontal lines representing maximum, minimum, and average value of the indicator over all past quarters. The colours of the lines are also based on the traffic light colours: red for the minimum value, yellow for the average value, and green for the maximum value. Figure 3-24 displays the implementation of these features.

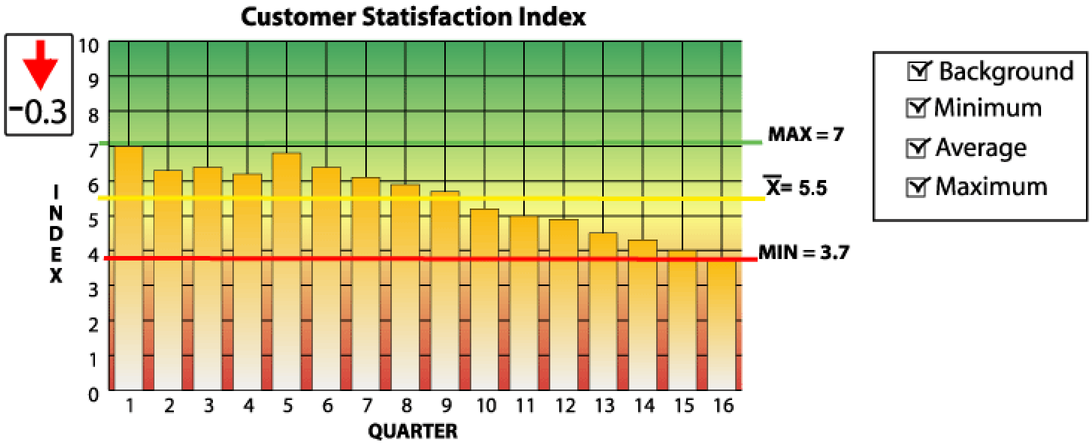


Figure 3-24. Visualisation of the customer satisfaction indicator.

3.2.3.5 Increasing alertness for value changes with iconic annotations

The icons presented in Figure 3-25 are used for indicating increasing, decreasing or stable averages over time. The arrows indicate the direction of the indicator compared with the previous time slice, their colour reflect the seriousness of the change.

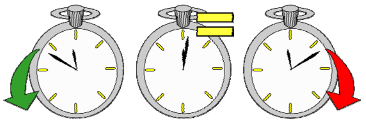


Figure 3-25. Three possible icons that indicate the change over time.

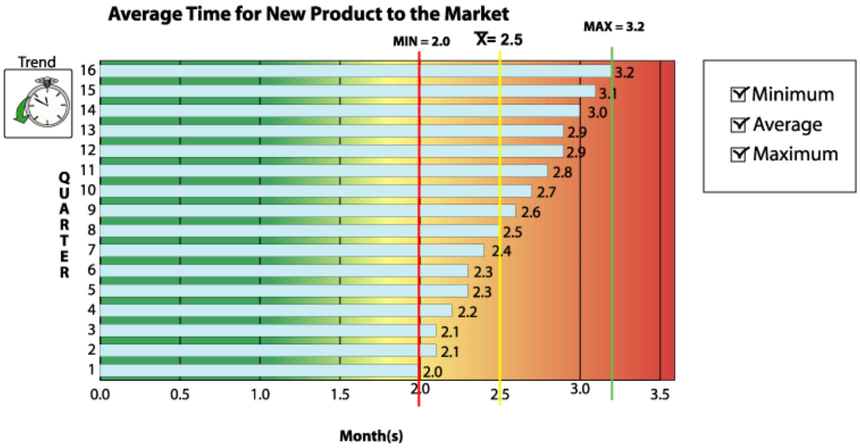


Figure 3-26. Visualisation of indicators of type time duration.

Figure 3-26 displays the implementation of the icons to increase the alertness for changes in the average time for bringing a new product to the market.

In the top left part of Figure 3-24 a red arrow and below it a number is displayed. The arrow is used also to increase the alertness for changing values. The variants of possible arrows are presented in Figure 3-27. The number below the arrow depicts the discrete difference between current and previous value.

Figure 3-27. Indicating changes of values.

3.2.3.6 Enhancing detailed understanding: text and number

Numerical information in charts

The major weakness of charts is their limited capability to communicate quantitative aspects of the data. Most of charts emphasise the qualitative values of the data. Ehrenberg (1977) suggested to add numerical information to charts to compensate for this weakness. However, one must remember that adding numerical information to charts will also burden the comprehension effort.

We added detailed information regarding the values by giving textual and numerical information as the secondary display (see Figure 3-28). Adding numerical information in the secondary display intends to provide more detailed numerical information of the data being presented – in this case displaying the components of the total operating expenses indicator.

Moreover, numerical information of data points is also given at the top of each data point in some charts when necessary (see Figure 3-26). Yet the rationale for providing numerical information of data points is depending on the type and characteristics of data being displayed. This feature can be manipulated by the user, to reduce the density of information in a display, with the smart legend (see page 81).

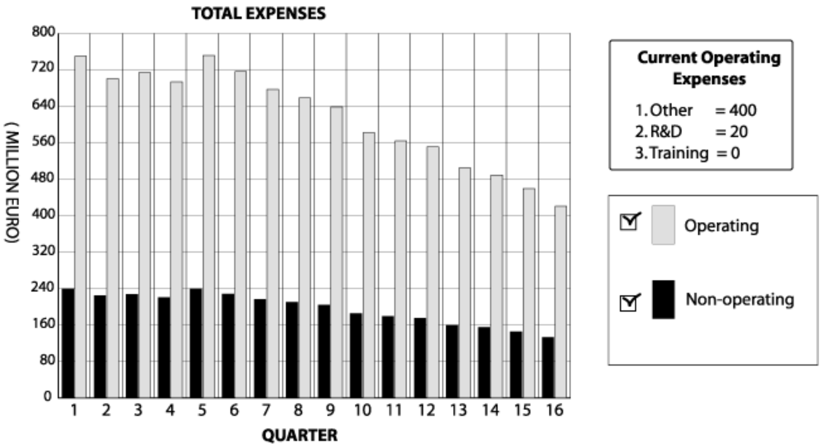


Figure 3-28. Visualisation of expenses indicator.

3.2.3.7 Reducing complexity of data values

Scaling

Reducing complexity of large variable values is a necessary step to visualise the data in charts meaningfully. The purpose is not only to increase readability of data being presented using simple alphanumerical magnitudes, but also to reduce the length of the y-axis and its values. We applied the scaling technique to the indicators that are associated with a large number such as expenses, profit, and turn-over (see Figure 3-28).

Textual information in K_Map

Textual information generally adds to the comprehension of visual objects. The K_Map displays two groups of knowledge processes indicators: effectiveness and speed. The former is mapped to the colour filling of the K_Map surface. The latter is visualised as simple textual information cues. Since we expect that players will comprehend the K_Map instantly by looking at the colour and other textual information, we decided to reduce the scaling steps of the speed indicator from 10 scale values to only 5 scale values as follow:

- S = vs; means very slow (index 1 to 2);
- S = s; means slow (index 3 to 4);
- S = m; means medium (index 5 to 6);
- S = f; means fast (index 7 to 8);
- S= vf; means very fast (index 9 to 10).

Figure 3-18 displays the application of this textual information. As we can see, the textual information that represents the speed is attached to the colour of each section of the surface.

3.3 Concluding remarks

Two topics were presented in this chapter: implementation of a gaming simulation approach in KM Quest and the use of visualisation strategies to support the collaborative playing and learning process in the simulation game.

The first topic is presented as a specification of the claim that gaming simulation is an appropriate approach to support collaborative learning of KM while at the same time supporting the organisational learning process. The effectiveness of simulation and gaming itself to collaboratively teach KM compared to other learning solutions is, in fact, beyond the main concern of the dissertation.

The second topic of visualisation of the game indicators is the central one of this dissertation. Visualising game or business indicators is basically about visualising numerical information meaningfully. In this chapter, we discerned two types information: entirely visual information such as in graphical charts and diagrams that qualify the numerical information, and visual information that only organises the numerical information to obtain quantitative information such as in numerical tables. The effectiveness of both types of visualisation strategies is a subject of discussion by various scholars in visualisation research as well as in organisational decision making and cognitive theories.

It is interesting to see how gaming and simulation can represent the reality and complexity of organisational situations. The same conclusion can be drawn that visualising the game indicators of business games is similar to visualising business information in general, although with some down-to-earth limitations. If these two parallel issues can be synchronised and verified scientifically, the result of the research in this dissertation might also contribute to the domain of simulation and gaming as well as to visualisation in gaming and business information systems in general.

Theoretically, the visualisation strategies described in the previous sections emphasise many cognitive and communication factors of group decision making. It is expected that the effective and efficient design of visualisations will have positive impacts on collaborative reasoning and thinking. This will lead to a better performance of game tasks when learning KM collaboratively. These predictions are going to be investigated as the main topic in this dissertation. However, before we can conduct this investigation in depth some initial questions, which are always present in a prototyping approach, must be addresses: first, whether the players find the visualisation easy to use, friendly, and also useful in the overall playing process; second, whether the comprehension of the visual artefacts is done collaboratively or individually; and what the use of the game indicators is for the overall playing process. A preliminary study will be done to answer these questions before we can conduct the in-depth investigation. Another important reason for conducting a preliminary study is the necessity to create and test a methodological analysis framework, which is not self evident given the topic and approach of the dissertation. A meaningful investigation of the topics using KM Quest, can only be undertaken when the system and the research methods have been tested.

In the next section, this preliminary study will be described.

4 A Preliminary Study: Visualisation and communication in collaboration

At the time when designing the visual representations for KM Quest was done, it was not clear to us when we could implement our visual designs in the real KM Quest gaming system because the prototype was technically not ready. However, it was decided to evaluate the visual designs and try to investigate their contribution to the collaborative playing process in an approximation of the future environment. To achieve this, a special KM web-game was developed.

In this section we call this game the KM Game to set it apart from the KM Quest system as described in Chapter 3. The KM Game does not use an underlying simulation model. Instead, predefined changes of game indicators are used, because the game engine (business model) of KM Quest was not ready. As a consequence of this, the gaming system can show only very limited and pre-canned changes of the indicators. The scenario of the game was designed to be as similar as possible to KM Quest; therefore the KM Game also uses game components such as the Coltec case description, the game indicators, information support, an embedded chat system, and Internet as the playing medium. The details of the gaming system used in this study will be described in Section 4.2.2.1.

4.1 Goals of the study

This study was mainly conducted to achieve the following goals: (1) evaluating the chart designs to obtain feedback about them; (2) obtaining information about the playing activities and the use of game indicators (visualised by charts and a numerical table); and (3) obtaining information about the appreciation of the players of the overall playing sessions.

Another goal was to investigate the suitability of the measurement strategies and instruments that are going to be used in experimental studies.

Based on the above goals, the research questions for this study were:

- Are there any general difficulties related with the design of the charts and the playing process? Are there difficulties in understanding specific charts?
- What is the role of the game indicators in the group decision making and playing process? How do players share the information derived from the charts during the playing process when deciding on game interventions?
- Do players try to comprehend the charts or the numerical tables collaboratively?
- What is the difference in the quantity of the decision outcomes and the use of the game budget in playing sessions in different groups?
- How satisfied are players with the overall playing process in terms of the group decision making session? What is the difference in group decision making satisfaction between players who are supported with charts and tables?
- What is the quality of the measurement strategies and instruments used? What improvements and changes are necessary for the experimental studies?

4.2 Design of the study

The intention of this study is mainly explorative – to find out how to understand a phenomenon. We added the elements of experimental design methods to the study in order to investigate detailed and controllable measurement procedures and to analyse the data obtained from the explorative methods. The design of the study is quasi-experimental, with two independent experimental groups.

Two conditions, Table (T) and Chart (C) group were formed. There was no difference in the game environment, materials, and other factors between the experimental conditions, except for the visualised representation of the game indicators. The teams in the T condition had access to numerical tables that consist of 13 quarters (see the example in Figure 4-4). The teams in the C condition had access to the chart representations that also consist of 13 quarters (see the example in Figure 4-3).

4.2.1 Participants

An advertisement for a half-day KM training with a gaming session was published four weeks prior to the data collection. In the advertisement, we asked for the participation of those who had never learned KM or other types of KM games. We were looking for only beginners in KM and also KM games in general. This selection was driven by the need to have rather naïve subjects as the bottom line, to initially test the quality of the visualisation, the playing process and the measurement instruments. The assumption is that these subjects are a kind of "worst" case, if they can work with the system than, presumably, everybody can.

Twenty-one international students from the international post-graduate programs of the Faculty of Educational Science and The Faculty of Technology and Applied Mathematics of the University of Twente registered voluntarily. All subjects were randomly assigned to seven experimental teams (3 players in each team). Then, each team was randomly assigned to one of the experimental conditions. Since there were only two experimental conditions in this study, the number of teams in each condition was unequal. However, we assume that the difference of one extra team will not influence the findings.

4.2.2 Instruments

4.2.2.1 The learning environment: KM Game

As mentioned before, the KM Game that we were using was developed particularly for this explorative study. The main architecture of the KM Game is depicted in Figure 4-1. Although it was designed in a rather simple way, the architecture of the system was intentionally designed to resemble the architecture of KM Quest (see Figure 3-2 in chapter 3). The main components of the system such as: visualisation of the game indicators, business case descriptions, the list of interventions, and the chatting facilities were implemented in WWW (World Wide Web) technology and mediated by Internet.

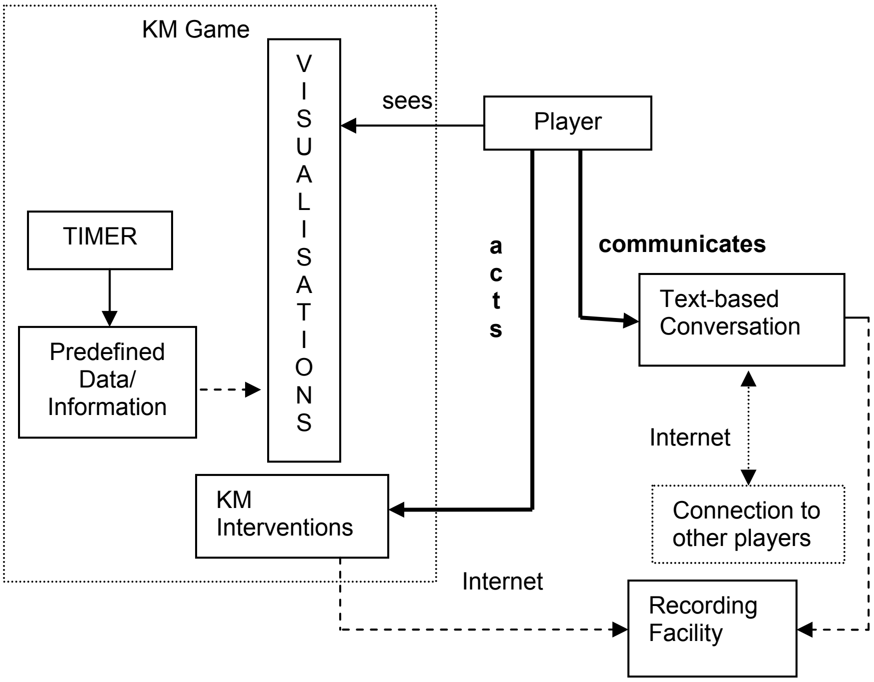


Figure 4-1. The architecture of the KM Game.

The learning environment was implemented in a website that combines hypertext pages (HTML), JavaScript, and Java applets (see the interface in Figure 4-2). We had to build two identical game systems for the table (T) and chart (C) conditions, except the representation of the game indicators. The game should be predefined to an experimental session of 13 quarters (15 minutes each), which is equivalent to a total of 3 hours and 15 minutes. This extensive playing session was deliberately chosen, as it was expected that future experiments would also need this time in order to be able to investigate the main research questions.

Location: http://130.89.50.195/bs3/viscom2/visual/index.html

INTRODUCTION

WELCOME

This site is used for experimental purposes only. Most of the content in this site is taken from the KITS Project. The copyright and courtesy of all materials will go the KITS Project.

The main mission of this game is to secure a company called COLTEC from bankrupcy and also expanding their market and making profit if possible. With the help of Knowledge Management approach, you can help the people in COLTEC to get a better life. COLTEC is a fictitious chemical company, which is struggling to expand their market in Europe.

The key of playing this game depends on agreements among you as a team about the intervention to safe COLTEC. The interventions will be effective and efficient if other team's members also agree with you. And every intervention will cost some money. It is important to be efficient in spending money, since each of you only have limited budget about 500000 euro.

Do not be afraid being critical to your friends, because everyone is still learning.If you are not familiar with Knowledge Management, also not to worried, because everyone in this game is new to this topic. You have to learn together in order to understand Knowledge Management.

The first goal in the game is to learn and practice a (general) systematic approach to problem solving in the KM domain. Knowledge about a systematic approach for problem solving is only useful when the task performer also possesses or acquires knowledge about the related concepts and principles. Acquiring this conceptual knowledge is the second goal of the game.
In the KITS learning environment a business simulation is used to make the game more realistic. Learning the principles and concepts on which this simulation model is based, **is not a learning goal**.

Good Luck!

Figure 4-2. The main interface.

As showed in Figure 4-2, the main interface of the KM Game is pretty straightforward. It is not the same as what was presented in chapter 3. There are two reasons for this: (1) due to slow progress of KM Quest system development we were not able to create an interactive interface as defined in KM Quest, and (2) also the purpose of this study, verifying the playing process and the design of the charts, precludes the need to design a fully interactive interface for the preliminary study.

In principle, the web pages were developed using part of the original KM Quest materials. We also modified and simplified the case description, the events and indicators. The modification of material did not affect the general line of the case descriptions, save for simplifying the amount of information such as a shorter history and description of Coltec, less business indicators, and a very limited number of game events. We selected 5 events which are representing 3 complex events and 2 rather simple events. During the playing session, these events were triggered sequentially in quarters 1, 3, 5, 8, and 10. The original list of 56 game interventions was used in this game. Each selection of an intervention always decreases the game budget. This list was also used to record players' final decisions concerning the game event.

Given the amount of time for conducting this study, a set of 31 game indicators was selected from the total set of 82 based on: (1) an equal representation of types of charts, (2) relevance of the indicators for the selected events, and (3) an equal number of indicators in proportion to each layer of the BM (see for these layers in Figure 3-6).

To create a "dynamic" effect of the game, these selected indicators must change their value in 13 quarters. These values were generated manually by the experimenter after consultations with KM experts and the BM designer. An example of a chart for game quarter 10 is presented in Figure 4-3 and an example of the numerical table for game quarter 9 is presented in Figure 4-4.

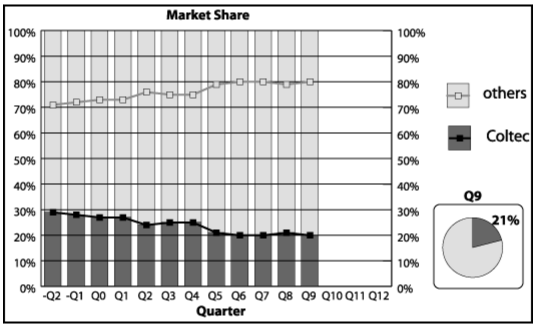
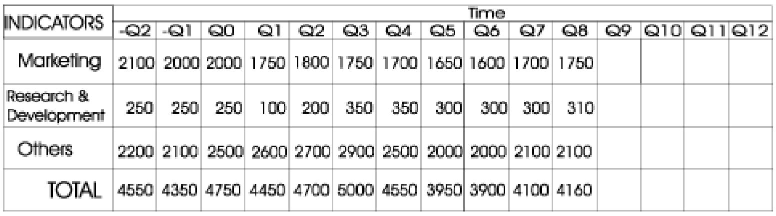


Figure 4-3. An example of the graphical chart in the C condition that represents the market share of Coltec.



INDICATORS	Time														
	-Q2	-Q1	Q0	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Marketing	2100	2000	2000	1750	1800	1750	1700	1650	1600	1700	1750				
Research & Development	250	250	250	100	200	350	350	300	300	300	310				
Others	2200	2100	2500	2600	2700	2900	2500	2000	2000	2100	2100				
TOTAL	4550	4350	4750	4450	4700	5000	4550	3950	3900	4100	4160				

Figure 4-4. An example of the numerical table in the T condition that represents the expenses of Coltec.

The JavaScript was used as a timer that triggered predefined game events and changed the content of the game indicators as presented in numerical tables or charts. The timer used an absolute time reference; it paced the game environment consistently as planned in the game scenario. This method gave a feeling that the users were working in a shared environment (see Figure 4-1). However, we are aware that the weakness of this predefined scenario is that players can easily discover that the game contents are predefined when he/she does not do anything. But this was seen as a minor problem given the goals of this study.

The major difference with KM Quest is the unavailability of the instructional support and the model of KM as shown in Figure 3-4. The instructional support, such as the worksheets, voting tools, and so forth, were not implemented in this game except providing supportive information, due to technical reasons and a limited need for these materials in this study. This also holds for the KM model, due to the developmental process of creating a generic KM model, the KM model used in this game was slightly different (see Figure 4-5). The players were asked to solve the KM problems found during the game based on this abstract model. We were aware of the risk that the players might not follow this model because the model is too abstract and the players might not understand how to follow the decision making process in the game. However, we thought that this model would provide a basic guideline and structure on how to proceed in the decision making process. In any case, the emphasis in this study is more on evaluation of the playing process than on mastering the KM model.

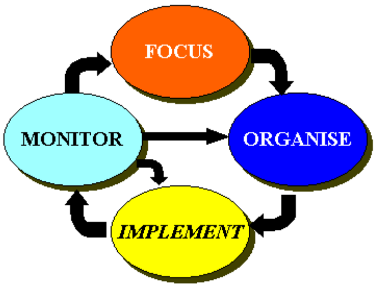
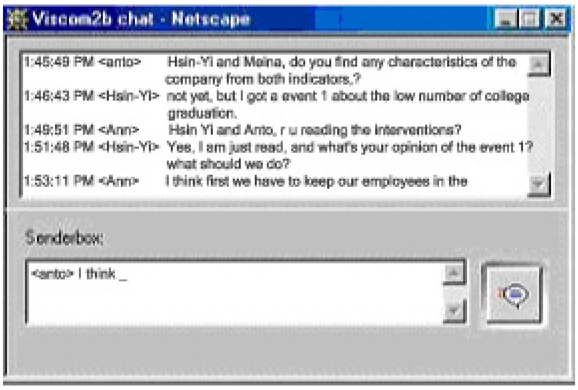


Figure 4-5. The KM model used in this study.

A text-based chat service was embedded in the KM Game to maintain a text-based collaborative communication process between the three players synchronously. To activate the chat system, a player must click a button in the interface. A new chat window will be opened in a separate window (see Figure 4-6). In this window, a player can see all the history of the messages and the names of the other two players. They can type their chat message in the "senderbox" and send the message by pressing the button next to the sender box.



```
1:45:49 PM <anto>    Hsin-Yi and Meina, do you find any characteristics of the
                     company from both indicators,?
1:46:43 PM <Hsin-Yi> not yet, but I got a event 1 about the low number of college
                     graduation.
1:49:51 PM <Ann>     Hsin Yi and Anto, r u reading the interventions?
1:51:48 PM <Hsin-Yi> Yes, I am just read, and what's your opinion of the event 1?
                     what should we do?
1:53:11 PM <Ann>     I think first we have to keep our employees in the
```

```
<anto> I think _
```

Figure 4-6. The chat facility.

A limited support section was also implemented in the KM game, which consists of the game help, KM theory, and the description of the game rules.

4.2.2.2 Study materials

Because the training module was not available, an extensive off-line game manual was made particularly for this study. This manual was developed by using the support information which is also available from the KM Quest website and an instruction manual to use the system and the chat tool. Information about KM theory and the general KM model for a generic problem solving strategy was also included in the manual.

In order to support playing, this manual was published two days prior to the data collection session. All participants were instructed to read and understand this material as much as possible.

4.2.2.3 Computer facilities

All participants used the same PC: Pentium II 233 MHz, 128 MB RAM. The computer is equipped with 17” SVGA colour monitor. For this study we used the Netscape Navigator^{TM} web browser version 4.78 because its stability and consistency to run advanced environments of HTML (version 4.0) with JavaScript and Java Applets at that time.

The computer room is divided into 5 sections by room partitions. We mixed participants from different teams and located them into each section. With this room setting each member of a team was located separately. There was no visual and auditory contact between members of a team.

4.2.3 Observation and measurement tools

Three main instruments were used to collect data: A paper and pencil multiple-choice test and questionnaires; recording facilities/ log files; and semi-structured interviews. The observation and measurement tools are used to obtain information about: (1) the background of the players; (2) players’ evaluation of the design of the charts; (3) the playing process; and (4) players’ evaluation of the playing process as a group decision making session. These measurements strategies were chosen to fit the purpose of evaluating the design of the charts and the other goals.

4.2.3.1 Background of the players

The background information about the players that we need to include in this study is general information about age, education, and gender; and also their ability to construct and interpret charts in general. To obtain the information needed we used: (1) a log file from the web filling form that records background information about the players; and (2) a multiple-choice test which is a combination of TOGS (Test of graphing in Science) from McKenzie & Padilla (1986) and TIPS II (Integrated Process skill test) from Burns, Okey, & Wise (1985). The newly constructed test received a new name as TOGS+. This test consists of 32 questions (26 questions from TOGS and 6 questions from TIPS II). The maximum score on this test is 32 points. This test is administered to measure graphing skills in science. Originally, TOGS measures the basic ability of (line-)graph construction and interpretation skills in science domains. It means that people who can achieve high test scores are those who have better skills to find relationships between variables and qualify these relationships (McKenzie & Padilla, 1986). We use this idea to predict graphing skills for the studies in this dissertation. This is necessary, because the evaluation of charts can be influenced by differences between people in their ability to understand graphs. These differences could lead to evaluations that more depend on graphing skills than on the designs themselves. Based on a pilot study that was done to construct the TOGS+, the time required to finish this test was maximal 30 minutes. At that time, the reliability coefficient, as measured with Cronbach’s alpha, was .76.

General information of the players such as age, gender, and education, was also obtained in our observation to see if they are comparable in each experimental condition.

4.2.3.2 Players' evaluation of the design of the charts

The measurement strategy used to collect data of users' evaluation is a questionnaire. The questionnaire was administered only to the C condition to obtain players' evaluation of the charts, because this was the focus of the study. The information from this questionnaire was expected to provide feedback to refine the visual design. The questionnaire consists of 25 questions: 20 Likert-like questions (5 levels from agreement to disagreement, and positive to negative evaluation) and 5 open questions. The questionnaire measures participants' evaluation in several categories: (1) general impression of the charts, (2) quality of the information, and (3) other technical design elements – such as background colour, textual information, statistical features, etcetera.

4.2.3.3 Playing process

Two log files record chatting sessions and the browsing/navigating activities of players. Both were obtained from the web server. These data registration files are used for a detailed observation of the playing process, in particular the frequency of requesting the web pages that contain the visual representation of the game indicators and the content of the text-based chatting sessions that are related with the use of the game indicators and other playing strategies. We need this information to analyse relevance and importance of the game indicators for the collaborative decision making process.

4.2.3.4 Players' evaluation of the group decision making process

For this purpose we use a questionnaire to obtain players' satisfaction with the group decision making session and a semi-structured interview.

The questionnaire used is a modification of the questionnaire from Briggs & de Vreede (1997) that measures a satisfaction index with group decision making meetings on three dimensions: (1) satisfaction with the decision making process; (2) satisfaction with the decision outcomes; (3) satisfaction with the support and facilitation during the process of decision making. In this questionnaire, players were asked to report their individual satisfaction based on these 3 dimensions after playing the KM Game. This questionnaire consists of 13 questions on 5 level Likert-like scales (strongly agree, agree, neutral, disagree, and strongly disagree). The original questionnaire was adapted to the purpose of the study because it was originally developed to measure participants' satisfaction with decision making in face-to-face meetings, for instance in managerial decision making meetings.

The semi-structured interview was held to obtain more detailed comments. Two players were selected randomly from each condition and invited to the interview independently a day after the playing session. They were asked the following questions: (1) What is your general impression about the playing session and learning materials; (2) What kind of problems did you encounter during playing; (3) What are your suggestions to improve the game system and the overall gaming session?

4.2.4 Procedure of the experiment

The experimental session for each condition was held on two separate days. The participants were invited to join the gaming session in the computer laboratory of faculty of Educational Science and Technology of the University of Twente. At the day of the data collection, they were informed that they would first had to follow a KM training session and would later play a collaborative game, called KM Game, for about five hours including the test session and twenty minutes for the lunch break.

After doing all necessary technical preparations, the participants were allowed to enter the computer room. Each of them received a unique identification number, a sitting location number that corresponds to the identification number of the computer and a copy of the game manual for those who forgot to bring the game manual that was distributed in advance.

The experiment started with a brief introductory session and a slide presentation about KM theory, an example of a game event and a problem-solving strategy to solve the game event. This introductory session was concluded with an overview of KM Game, and a practice session to use the chat system. This introduction was given by the experimenter.

When there were no questions asked anymore, the TOGS+ was administered. After finishing this test, players started the game session by first filling the web form that collects information about the background of the players. The contents of the form were verified by the system and used to assign each participant to the KM Game web site and login automatically into the chat system. If this procedure is done properly, participants will enter the corresponding experimental condition and be able to see the names of the other two team members in the chat room. Then, the players were asked to begin the conversation by introducing themselves and then start browsing the KM Game system.

At the beginning of the game, the participants were informed that each participant received 500,000 Euro (virtually) as their personal game budget, which can be spent to buy KM interventions in solving Coltec's problems. Thus, as a team of 3 players they have 1,500,000 Euro as the game budget. Although a player in a team had her/his individual budget, the way we assessed the budget used was based on the group expenditure. We instructed the players to "share" their individual budget in their own way because the system was, for technical reasons, not able to calculate it.

The members of a team must coordinate to select which intervention might be appropriate to solve game events and how to select the interventions economically. These two main tasks need a decision-making process and a negotiation about the budget. The participants were instructed to solve the problem as deliberately as possible and also to be critical towards other team members' proposals to avoid "mistakes" in deciding on KM interventions and use of the budget. The participants were advised to submit interventions not only based on events but also on the basis of a critical appraisal of the value of the game indicators. The beginning of the game was initiated by triggering the first event in the first quarter. The game continues until the playing process reaches the fifth event in the

13th quarter. At the end of the game session, participants were asked to fill the questionnaire(s) before leaving the computer lab.

4.3 Results

4.3.1 Background of the players

4.3.1.1 Demographic information of the players

The average the age of all participants was 28 years 11 months (s.d.= 5 years 7 months). Educational background is: sixteen participants hold a Bachelor degree and five participants hold already a Master degree. Other information about demographic data of participants is presented in the following Table 4-1.

Table 4-1. Demographic information of the participants.

Cond.	N(n)	Mean Age (year; month)	s.d. Age (year; month)	Gender	Education
C	3(3)	26; 8	5; 5	6 ♀	7 BSc.
T	4(3)	30; 11	5; 2	7 ♀	9 BSc.

Notes: *BSc. = holding Bachelor of Science degree.*

A general impression from Table 4-1 is that on average the players in the T condition are somewhat older and have slightly more male participants than those in the C condition. However, concerning their degree in education, there is not so much difference. Thus, we assume that the differences in the background of players will not influence the overall result of this study.

4.3.1.2 Checking graphing construction and interpretation skills

The results were obtained by the TOGS+ test. The reliability computed by Cronbach's alpha in this study is equal to .66. It is slightly lower than in the pilot study that was done while constructing this test, but this is well inside the margins.

The overall average score on TOGS+ is quite high (M=26.3, s.d.=3.36, N=21). It means that on average the players achieved 81% correct answers. When we compared the results in two experimental conditions, the averages of both groups are equally high. The players in the T condition showed a slightly better test score (M=27.1, s.d.= 2.84, N=12) than the players in the C condition (M= 25.2, s.d.= 3.87, N=9). The non-parametric Mann-Whitney U statistical test did not confirm a significant difference between two independent groups (z=-1.215, p=.224).

We concluded that all teams in the T and C conditions have equal and high skills in constructing and interpreting graphical charts. As a consequence, differences in evaluation and comprehension of the charts cannot be ascribed to differences in general graph comprehension abilities. However, one should keep in mind that though we aimed to use rather naïve subjects as a kind of "bottom line", this does not hold for their graph comprehension abilities.

4.3.2 Players' evaluation of the chart designs

The evaluation of the charts was obtained with a questionnaire that was given to the players in the C condition. The summary of the questionnaire is presented in Table 4-2.

Table 4-2. Summary of the visual design evaluation questionnaire.

	Aspects	M	(s.d.)
General Impression	General satisfaction	3.8	(.83)
	Useful	4.1	(.78)
	Easy to understand the charts	4.2	(1.39)
Quality of Information	Provide relevant information in playing	3.7	(.87)
	Sufficient amount of information depicted by the charts	3.9	(.93)
	Easy understanding of information depicted by the charts	4.3	(.87)
Technical design elements	Familiar with the type of charts	4.4	(.88)
	Consistency of the chart design	4.0	(.71)
	Understand the meaning of background colour	3.6	(1.42)
	Colour composition confusing	3.9	(1.05)
	Appreciate the background colour	3.4	(1.42)
	Readability of textual info	4.2	(.83)
	Easy to understand the textual information	4.4	(.88)
	Sufficient amount of textual information	3.7	(.87)
	The legend is useful	3.8	(1.20)
	The size of the charts is too big	3.4	(1.13)
	Appreciate the layout	3.4	(1.33)
	The range of the axes is enough	4.1	(.78)
	Expect more statistical tools	3.1	(1.05)
	Understand the meaning of the icons	3.7	(.71)

Notes: scores on a 5-point rating scale (1 = negative to 5 = positive).

Below is the resume of the chart evaluation form from the players of the C condition (N=9). The overall judgment for all evaluation categories was positive (all averages are at the positive side of the 5-point scales). In the category of general impression of the charts, the players were generally rather satisfied with the overall visual design (M=3.8, s.d.=.83). The players also reported that the charts were useful to play the game (M=4.1, s.d.=.78). Although there was some variance in reporting the appraisal of the easiness to understand the charts, the players reported positively (M=4.2, s.d.=1.39).

In the category of the quality of information conveyed by the charts, the players were slightly less positive about the amount of information (M= 3.9, s.d.=.93).

In the category of the other technical design elements, we noticed some problematic issues:

- The players judged that the overall composition of the colour is slightly confusing (M=3.9, s.d.=1.05). The players also reacted less positively to the question that asked whether they could understand the background colour (M=3.6, s.d.=1.42). In almost the same way, participants judged that they appreciate the background colour slightly less positive (M=3.4, s.d.=1.42).

However, we noticed that there is some variance in the players' judgments on the colour categories;

- There was also an indication that participants felt the textual information was, to some extent, not sufficient to convey information (M=3.7, s.d.=.87);
- The participants somewhat judged that the size of the charts is too big (a negative item, M=3.4, s.d.=1.13);
- The overall consistency of the layout of the charts seems to be perceived less positively also (M=3.4, s.d.=1.33);
- the additional statistical functions in the charts were rather as expected (M=3.1, s.d.=1.05);
- The meaning of icons and symbols used in the charts were judged, to some extent, to be less understandable (M=3.7, s.d.=.71).

Above findings show that even though most of the technical design elements were judged positively, there are minor aspects that must be reconsidered in the design of the charts. Overall, the judgments were positive, indicating a successful application of the design principles from Chapter 3.

The other section of this questionnaire asked players to write their comments or any other general remarks in evaluating the chart design. Questions are: What is your overall judgment? Are there any charts that were disliked? Can you give suggestions to improve the design? Are there other expected visual functionalities? Answers can provide more specific information that can be used to improve the details of the design. A few players gave their reactions to these questions. Below is a brief summary of their answers:

Overall judgments. Four participants said that the overall designs are nice and colourful. One participant mentioned that the design is too colourful; one participant said that he liked the background colour. One participant said that he liked the overall designed, but only one chart required (number of employees) more time to be understood.

Charts that were disliked. Two participants mentioned that two charts displaying the number of employees and the production level were very confusing (the stacked bar-chart). One participant mentioned clearly that the different levels of measurement units confused him.

Suggestions. The following suggestions for improvement were made: change market share and productions charts into less complex ones; use the same size of canvas; make them more readable; every chart must have consistent colour and size; more textual information is needed; symbols and icons should be smaller; and reduce the contrast of the background colour.

Expected additional functionality(/ies). Zoom in and out facility, user-defined dimensional units of x- and y-axis, and emphasize the combination of line and bar chart.

The results from this questionnaire were taken into consideration when modifying and revising some of the charts.

4.3.3 Playing the game

As mentioned, observation of the playing process was done by using the data from the log files taken from the web server.

4.3.3.1 The profile of the playing activity

The log file from the web server records the frequency of requesting web pages by the players, the time stamp when a web page is requested, and the network address (I.P. address) of the player's computer. We use the frequency of requested pages as the indicator of the players' playing activity. Several comparisons in this section are purely explorative. Due to the small number of observations in each condition, we are unable to test all findings statistically. As a consequence, the results of these comparisons cannot be generalised in a straightforward way. They have to be interpreted as indicative for design problems and theoretical issues.

As a first impression, on average the activity level of requesting game web pages during the overall playing session is almost equal for both conditions. The T condition showed on average a slightly higher activity level (M=73, s.d.=28.91, N=12) than the C condition (M=72, s.d.=36.68, N=9). However, we observed that the variance of the activity levels among players within the experimental conditions is rather high, meaning that not all players were playing equally active. The Mann-Whitney U statistical test did not confirm a significant difference of the activity level between the experimental conditions (z=-.178, p= .859).

Below, Figure 4-7 displays the percentages of the particular web pages visited during playing KM Game. This figure displays the profile of the playing activities of players in each experimental condition.

From this figure of the distribution of the playing activity, we can see that the players in both conditions most frequently requested the web pages that are related to the main game tasks: business and knowledge indicators and selecting the interventions. Of course this behaviour is logical, because the players were instructed to solve together the problems posed by the game events by selecting KM interventions.

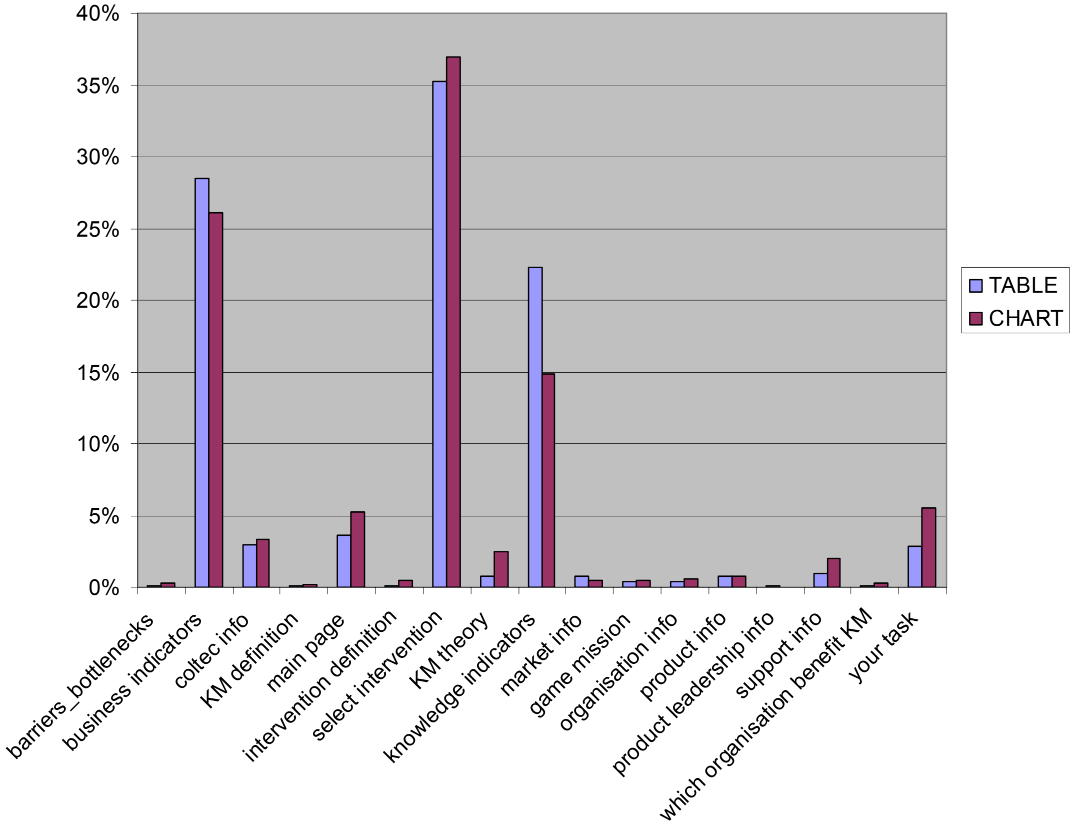


Figure 4-7. Distribution of the playing activities for both conditions.

We can see that the percentage of requesting the web page that consists of a list of KM interventions in the T condition is on average 35.2% (s.d.=.93%, N=12) from the total of activities. For the C condition the average is 37.0% (s.d.=1.41%, N=9), which differs only marginally from the T condition. Interesting results are found when looking at the average proportion of requesting web pages that contain business and knowledge indicators. The players in the T condition, on average, requested the web pages of game indicators slightly more frequently than in the C condition. The players in both conditions requested the web page that contains business indicator more frequently than the one with knowledge indicators. In accessing the business indicators, the players in the T condition were slightly more frequent (M=28.5%, s.d.=1.31%) than players in the C condition (M=26.1%, s.d.=2.49%). There is a big difference in the percentage of requesting the knowledge related indicators between the T and C condition. The T condition requested this web page more frequently (M=22.3%, s.d.=.93%, N=12) than the C condition (M=14.9%, s.d.=1.70%, N=9).

These findings indicate only the profile of the playing activity. They can not be directly taken as primary evidence to validate the use of the game indicators in the collaborative playing process. We have to enrich in our analysis these findings with the content of the chatting session to obtain evidence on how the players actually use the game indicators in the collaborative playing process.

4.3.3.2 Summary of the chat sessions: playing strategies

The data from the log file that records the chatting session are obviously very rich with textual conversations. At this exploratory stage of our study, there is no need to summarise the overall chatting session statistically. A general impression will suffice to get some insight into the ways players actually use the game indicators and what playing strategies can be identified.

Most of the conversational topics that are not directly connected with our research interest were neglected. These are topics like social conversations, a conversation about daily activities, examinations, jokes, and so forth. From the overall textual conversation in both conditions, we resumed only the important and dominant conversation, particularly those that are related with selecting and deciding on the game interventions. We did not try to differentiate the conversational topics between the C and T condition as this requires a more refined coding framework that should be developed after the exploratory study. Thus it is the goal of this section to summarise the conversation in order to detect a pattern in playing strategies.

From Figure 4-7, one can see that most of the activity of users was concentrated in requesting the web page of selecting the game interventions, it was found that the chat conversation topics were largely about selecting the interventions. The impression obtained from the chatting sessions is that all teams most of the time did not carefully elaborate the problem together. Most of the conversation was straightforward directed to select the interventions with some superficial considerations only. However, we could categorise the players' strategies when selecting the interventions from "the shallow or simple" approaches to the "complex or deep" approaches. We were particularly interested to see how the information taken from the game indicators becomes involved in the decision making process.

Below are examples of a chatting session within each category of approaches or strategies. They are ordered from "shallow or simple" to "complex or deep" chat sessions.

Category 1: Selection of the game interventions while using the game budget as the major consideration

The conversation topic in this category might be less relevant for our interest in the role of the game indicators in the playing process, but it occurred rather often in the chat sessions. In the example below, selection of the game interventions was done without considering relevant information, except the cost of the intervention.

Example:

Player5	*so first we focus on TQM and sales*
Player5	*the training for TQM is cheap and useful*
Player10	*Ok*
Player 10	*I'll install training for TQM*
Player 5	*it will only cost 50 ,000*
Player 5	*Good*
Player 5	*Agreed*
Player 10	*and for marketing???*

Notes: Above text is originally taken from a chatting session in the playing. It may contain some grammatical errors.

This approach occurs sometimes in the "pure" form as shown in the example, but also sometimes after considering other information which ultimately is neglected when making the decision.

Category 2: A direct translation of the game event to the selection of game interventions

In this category, the players tried to make a direct translation of the problem presented by the game event to the selection of an intervention as a solution for it. The players did not consider the game indicators as the other reason to select certain game interventions.

Example:

Player6	*okay.. lets we focused on event 1*
Player9	*so we need to change something within the company' culture to motivate employee*
Player6	*do we have to do an intervention about that news?*
Player 6	*yeah.. I agree.. but up to this time.. we do not know what to do right?*
Player 9	*yes, we need to submit an intervention*
Player 6	*<Sammi>, where are u?*
Player 6	*what is your suggestion?*
Player 14	*I am here*
Player 6	*please responds*
Player 14	*I am looking the interventions*
Player 6	*what do you worried much about this news?*
Player 14	*u mean the low graduation one*
Player 6	*it seem people, especially student do not have interest in chemical and related stuff*
Player 9	*yes.....let's see the list with intervention....*
Player 14	*so i think we need some training system*
Player 6	*which one is that?*
Player 14	*the 5th*

Notes: above text is originally taken from a chatting session in the playing. It may contain some grammatical errors.

Category 3: A direct translation of the game indicators to the selection of game interventions

In this conversation, the players did not consider the game event as a problem; instead they take the game indicators as the reason to select interventions.

Example:

Player 6	*no... I meant since our profit rise, but unfortunately our sales decrease...*
Player 6	*I just confuse how come profit rise but sales not?*
Player 6	*both of them have to be the same direction right?*
Player 9	*that's life....something can be unusual....so....no interventions now?*
Player 6	*Rise u the sales!*
Player 6	*I mean rise up the sales!*
Player 9	*ok....can you find such intervention within that list?*
Player 14	*so which intervention u prefer?*
Player 6	*contract marketing agencies....*

Player 14	*Okay*

Notes: above text is originally taken from a chatting session in the playing. It may contain some grammatical errors.

This type of conversation might initially begin with or is interspersed by sharing information about the interpretation of the game indicators. Below several types of sharing interpretation of the game indicators, derived from the chat sessions, are described:

1. Mentioning numerical data (no numerical interpretation). Example: "*look, our market share is 25%*"
2. Mentioning data patterns (interpreting range of data of the game indicator into trends). Example: "*our profit rise*"
3. Translating data patterns into subjective meaning (trend is up means data is getting better). Example: "*we should not worried to much because we still have enough employee.*"
4. Relating data to the event or other information taken from the game environment: possibly extrapolating efforts and finding a correlation between two or more game indicators and interpolating. Example: "*our profit rise, but unfortunately our sales decrease... how come profit rise but sales not?*", or "*if it [the status of indicator] continues like this, it may bring negative influence in the future*"

There were no indications that the players comprehended the game indicator collaboratively when they engaged in this type of approach.

Category 4: An indirect translation of the game event, mediated by game indicators, to the selection of game interventions: an indication of collaboration in thinking and communicating.

We also found there is a potential effort to find relationships between a game event and some indicators, although it was rarely found in the chatting session in both experimental conditions. This is considered to be a high level of a collaborative cognitive analysis and communication process, because relating the information taken from the game event and the game indicators to the selection of the game intervention requires a higher level of thinking and collaboration in communicating. As an example, an attempt to find a causal relationship between changes of values of the game indicators and an occurrence of the game event, and then finding appropriate interventions may fall into this category (see the example below).

Example:

Player 16	*According to indicators they are the knowledge transfer among the production staff is low*
Player 16	*we should not worried to much because we still have enough employee*
Player 16	*the issued is they have a low job satisfaction, so we've to retained them because we know that they weren't many graduates in the market*
Player 16	*<Cut> you don't have any comments?*
Player 24	*I agree with <Iwin> to do the recruiting*
Player 20	*I think the problem is not such a major problem, but we could invest in the joint recruiting program*
Player 16	*How much the joint recruiting program cost?*

Player 20	*80 000*
Player 20	*if you see the indicator, our resource in production is not too good.. there's just in mediocre level*
Player 24	*We could share the cost...is it possible*
Player 20	*n if it continue like this, it may bring negative influence in the future*
Player 16	*Wait*
Player 20	*so i think investing in the new comer, fresh graduates, and train them won't be a bad idea*
Player 16	*The new comer is marketing graduates it is not related, please read the interventions carefully*
Player 16	*the decreasing graduates is from science*
Player 20	*No…..they have 3, in marketing, production n R&D*
Player 20	*we chose the second one for production*
Player 16	*we should not worry about our knowledge research, (sorry)*

Notes: above text is originally taken from a chatting session in the playing. It may contain some grammatical errors. In the text, the code "<text>" means "<nick_name>".

This type of conversation will probably not occur unless all players in a team contribute their personal knowledge and understanding about the status of game indicators and the problem being solved to the group process. Thus, sharing information about the game indicators might also be a key to sharing knowledge about the problem being solved.

We can say that the overall chatting sessions in both the T and C conditions were found to be, rather unexpectedly, poor. Most of the chatting sessions belonged to the first three categories. There were hardly any chat sessions of the "complex or deep" type, such as category 4. However, with the unavailability of the instructional support and the poor real interactivity of the game indicators, this is maybe not too surprising.

4.3.3.3 Decision outcomes and use of the budget

The analysis of the playing activities is not complete without having clues about how the teams reach the decision outcomes. In order to quantify the decision outcomes, we decided to observe the average number of game interventions submitted and the use of the game budget during the playing process. However, the comparison done in this section is again purely explorative. Due to the small number of observations in each condition, we are unable to test findings statistically. In the same vein as before, results are indicative and not generalisable. It was found that teams in the T condition submitted on average 22.4(s.d.=5.9, N=4) interventions and used 1,435,000 Euro (95.6%) of their game budget, whereas the teams in C condition submitted, in average 19.3(s.d.=3.2, N=3) interventions and used 1,340,666 Euro (89.3%) of their game budget.

If we link this finding with the playing activities of the players in the experimental conditions (see Figure 4-7), it is interesting to observe that the players in the C condition visited the interventions page more frequently than the teams in the T condition, but in fact the teams in the C condition did not submit more interventions than the ones in the T condition. With this finding, we hypothesised that the communication process of selecting game interventions in the C condition may prevent the players to successfully select game interventions every time they visited the interventions page. Although we could not find direct evidence in the communication session among players in this study to support this assumption, we believe that the communication process to select game indicators in the C and T conditions is different.

4.3.4 Players' evaluation of the collaborative playing process

The results below were obtained by the questionnaire, which measures players' satisfaction with group decision making during the playing process, and the semi-structured interviews.

4.3.4.1 Players' satisfaction with the group decision making process

It was mentioned before that playing in KM Game is assumed to be a collaborative group decision making process. The questionnaire was used to obtain a subjective satisfaction measure (index) for the group decision making sessions on three dimensions: decision process, decision outcomes, and support facilitation during group decision making. The result of the questionnaire is summarised in Table 4-3:

Table 4-3. Group decision making satisfaction index

Cond.	GS	N	M(s.d.)
T	PROCESS	12	3.8 (.74)
	OUTCOMES	12	4.1 (.65)
	SUPPORT	12	4.2 (.63)*
C	PROCESS	9	3.2 (.95)
	OUTCOMES	9	4.0 (.67)
	SUPPORT	9	3.4 (.83)*

*Notes: the index is on a 5-point s rating scale (1 = unsatisfactory to 5 = satisfactory). The average scores on the Support dimension differ significantly at *p < .05 in the Kruskal-Wallis Test.*

Players from the T and C condition tend to judge the group decision making process equally positive. The same holds for their judgment about the decision outcomes arrived at during the group decision process. Regarding these two factors of the group decision sessions, there are no significant differences between both experimental conditions ($\chi^2_{process} = 2.698$, df=1, $p_{process} = 1.0$; $\chi^2_{outcomes} = .333$, df=1, $p_{process} = .564$). The significant difference is found in the players' satisfaction with the support or facilitation of the game system for the group decision making process ($\chi^2_{support} = 4.343$, df=1, $p_{support} = .03$). The players from the C condition judged the facilitation or support from the system less positive ($M_{Ccond} = 3.4$, s.d. $_{Ccond} = .83$) than the players in the T condition ($M_{Tcond} = 4.2$, s.d. $_{Tcond} = .63$).

The support category consists of three questions that ask about the satisfaction of the players with the effectiveness, sufficiency, and positive influence of the support. In a closer analysis, the findings confirmed that players in the C condition judged the content of the system to be less sufficient ($M_{Ccond} = 3.4$, s.d.$_{Ccond} = 1.01$, N=9) than players in the T condition ($M_{Tcond} = 4.3$, s.d. $_{Tcond} = .65$, N=12). Moreover, the players in the C condition judged that the facilitation or support of the system provided a less positive influence on group decision making ($M_{Ccond} = 3.3$, s.d. $_{Ccond} = 1.12$, N=9) than players from the T condition ($M_{Tcond} = 4.3$, s.d. $_{Tcond} = .89$, N=12). Both conditions judged the effectiveness of the support for the group decision making almost equally positive (M_{Ccond}= 3.4, $s.d._{Ccond}$=1.01; M_{Tcond}=3.9, $s.d._{Tcond}$=.90).

We conclude that the overall satisfaction in the T condition was slightly higher compared with the C condition (Table 4-3 shows that all average scores of the T condition are above the average scores of the C condition), particularly if we look at the difference in the satisfaction with the facilitation support in the system. This could be due to the way the information of the game indicators is displayed, but as information from these was hardly used in the decision making process, this seems unlikely. However, one could argue that the general "look and feel" of the visualisation will contribute to a more positive overall judgment about support, even without the actual use of the information in the decision making process.

4.3.4.2 Summary of the semi-structured interviews

Below are the summaries of the interviews that were held a day after the data collection. Four participants were interviewed separately.

The two players from the T condition gave the following answers:

(1) *What is your general impression about the playing session and learning materials?*

Both participants reacted positively; they thought that the general approach in studying KM with gaming was a good idea. However, after playing the game they still did not understand what is the KM problem-solving strategy used in the game. Participants complained that the study material was too abstract and had too much information, they would like to have more time to read the study material before playing.

(2) *What kind of problems did you encounter during playing?*

The playing process was perceived as a difficult task, especially to communicate to each other using the chatting tool. Both players said that it took them awhile before they could finally master control over the chat system while at the same time browsing the game environment. This happened because the chat tool is not in the same window as the main interface (see Figure 4-2 and Figure 4-6), so the players had to switch between the main interface and the chat window.

(3) *What are your suggestions to improve the game system and the overall gaming session?*

Both players were reluctant to give the answer. However, when they were asked their opinion about a possibility to implement charts instead of only the numerical tables, one player said that combining the numerical table with charts or diagrams would be positive. But the other player said that the detailed information in the numerical tables was rather useful.

The two players from C condition gave the following answers:

(1) *What is your general impression about the playing session and learning materials?*

Participants reacted positively, they liked the idea of gaming for teaching KM. However, they still perceived KM to be a difficult domain to understand. They thought that the game was similar to other decision making processes. One of participants said that he did not see the difference between a KM problem-solving strategy and other problem-solving strategies. The learning material was perceived to be helpful, but difficult to master in such a limited time. Some typo-errors and inconsistency of terms used in the game manual were detected by one participant. One of the participants asked whether the game system was real or not, because he suspected that the game indicators did not show any improvement even though he assumed that the decisions taken by his team were correct.

(2) *What kind of problems did you encounter during playing?*

Both players mentioned that the biggest problem was again about handling the chat system which was not embedded in the main interface of the KM Game. One of the participants said clearly that she did not like the idea to switch between the chat box and the web page of KM game. She also complained about the limited numerical information conveyed by the charts. She said that the game indicators are interesting but lack numerical information.

(3) *What are your suggestions to improve the game system and the overall gaming session?*

The participant who complained about the lack of numerical information in the charts suggested to add more detailed data points to the bar columns or plots of line charts and simplify the clustered bar charts. He found the clustered bar charts too difficult to understand. Another participant said that for future developments he expected more information in the charts that shows the effect of the selected game interventions on the game indicators directly.

From this summary it is evident that the chatting tool, which was positioned in an independent window separated from the main interface, made playing and communicating difficult. This is probably because they had to switch their attention between the game window and the chat window. The players in the T condition described clearly that they needed sometime to get used to switching windows.

The implementation of the charts in the game was judged positively, to some extent, by the C condition interviewees. The players in the T condition did not clearly mentioned if they would expect charts to replace the numerical tables.

4.4 Conclusion

We order the conclusions according to the goals of this study and its specific research questions. Most of the comparisons of the findings in this study were not statistically tested. As a consequence, the conclusions below have a limited value for generalisation.

The first research goal was about evaluating the chart designs in order to obtain feedback about the design. The research questions were: Are there any general difficulties related with design of charts and the playing process? Are there difficulties to understand certain types of charts?

We can conclude that we did not find major difficulties in understanding and comprehending the charts, except for the stacked-bar chart. Overall players' appraisal of the design of the charts was positive and we were satisfied with the positive reactions of the players who said that the charts were easy to understand and useful to play the game. Some design elements, like the range of the x- and y-axis, the quality of textual information were also judged positively. Despite this positive reaction, some visual elements were still seen as problematic.

Regarding the type of chart, the stacked-bar was seen as difficult to understand and confusing. This was probably so because (1) the differences in height of slices of the column which actually represent proportional changes in the data overtime, was too difficult to be understood; and (2) in our design the distance between two or more stacked-column was too small (see Figure 4-8).

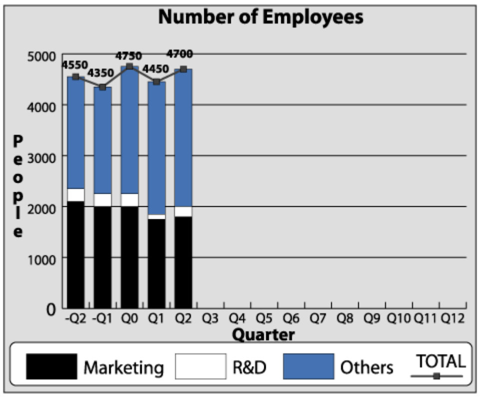


Figure 4-8. An example of the problematic stacked bar chart.

Another important issue is the amount of textual information that accompanies the icons or other symbols used in the canvas. It seems that players still needed more textual information to support their comprehension. This certainly is taken up for further development.

One of the best known problematic issues is the use of colour. We knew that the appraisal of colour is always subjective; however, some properties of colour sometimes are just too problematic for eliciting a particular understanding. For instance, the brightness of the background colour was judged as potentially disturbing the player's effort to make sense of the meaning of the colour. In the next implementation of the charts, we obviously have to reduce the brightness of the background colour in order to provide figure and ground effects for the representation of the plotting and the background colour, and attach a possibility to remove the background colour from the display interactively. Another issue related with the use of colour is the consistency of the colour that represents a group of indicators. Although we had done some consistent colour mapping it was still perceived as being inconsistent.

Additional statistical features in the chart seem to be sufficient. We decided not to add extra features.

Other minor aspects, like size of the canvas, are also taken into account in the future development of the real game. It is understandable that the players would like to have a small or medium sized chart canvas because the current visual design was a static visual representation (image) due to the unavailability of the interaction features in the chart canvas. The static visual representation might be perceived as rather dense with visual objects.

One general remark during the overall evaluation in this study referred to using a static visual representation. We expected the result of this study to be much more positive if the interactivity of the chart design is implemented, giving the user control over different features of the charts. We suspect that the negative appreciation of the visual elements is mostly caused by the density of the visual information and the absence of possibilities to change this.

The second research goal was to obtain information about the playing activities in relation with the role of game indicators in both experimental conditions. The research questions were: What is the role of the game indicators in group decision making during the playing process? How do players share the information derived from the charts during the playing process? Do players try to comprehend charts or numerical tables collaboratively? What is the difference in the quantity of the decision outcomes and the use of the game budget in different experimental groups?

We conclude that players in both conditions often *accessed* the game indicators in the playing process. There was not much difference in the frequency of requesting web pages that contain the business indicators between the two experimental conditions. However, we detected that the players in the T condition showed more activities in requesting knowledge indicators web pages than those in the C condition. On the other hand, the C condition seems to be more preoccupied with the business indicator web pages than with the knowledge indicator web pages. We did not find specific information in the data to explain this behaviour. However, we further hypothesise, based on our theoretical considerations, that it could be related to the changes of the data points in the graphs which are visually more compelling and may be more easily remembered than changes of the numerical information in the tables. This can be exacerbated because the values of the business indicators have a much wider range than those of the knowledge indicators which is limited to an index from 1 to 10. Thus, in the C condition players could easily understand the charts in the category of the knowledge indicators. The density and complexity of the numerical information in the numerical table is not easy to understand at a glance, with the consequence that the players in T condition requested these web pages over and over again.

Another aspect regarding the playing process is the frequency of requesting the web page that contains the selection of the game interventions. This was one of the main tasks in the overall playing process. It was found that the teams in the C condition on average requested this page more often than those in the T condition, but the players who were supported with the charts, on average, submitted fewer interventions and used less of the game budget during the overall playing process. This could indicate that agreement in deciding about selecting the interventions in the teams who were supported with the charts was rather difficult to achieve compared to the teams who were supported with the numerical table. This finding is rather surprising and contradicts our theoretical framework that predicts that graphs will support the decision making process better than the numerical table.

The *use* of the game indicators was evident in the chat sessions, particularly when the players engaged in the communication to decide on the selection of the intervention, although this did not occur very often. We found that there were some ways of using the information from the game indicators in the discussion to select the game interventions: a direct translation of their value to the selection of the game interventions and an indirect translation of their value through the events in selecting the interventions. The latter was found to be very rare, maybe because it needs a higher level of collaborative thinking and communicating than observed in the study.

The process of *comprehending the charts collaboratively* did not occur. It is concluded that the players tend to share only the results of their individual comprehension – that is their individual cognitive interpretation of the numerical information from the visual representation of the game indicators. It seems that the players were not inclined to comprehend the game indicator collaboratively because the comprehension process was not easy to do in a chatting session and would probably create divergent interpretation among players. It is probably difficult for the players to get involved in such a communication process.

The third research goal was the appreciation of the players of the overall playing sessions. It was found that the players in the T condition were more satisfied with the overall group decision making than players in the C condition. A significant difference was found in the players' appreciation in the C condition of the facilitation or support from the system. They stated that the content of the facilitation is not sufficient and had less influence on the overall decision process. We suspect that this has something to do with the difficulties in the comprehension process of the charts, which probably did not went smoothly due to a lack of textual and numerical information. This reminds us of the concept of arbitrary symbols in information visualisation as stated by (Ware, 2000) and our specific design principles in chapter 3. In this study the prototype used several charts that did not show detailed textual and numerical data information. We decided to add more textual and numerical data information in revising the charts in the real KM Quest system.

The overall collaborative playing process was appreciated more positively by the teams who were supported by the numerical table. However, in this study we do not consider that the players who were supported by the numerical table would learn KM much better than those who were supported with graphical charts. In our preliminary analysis of the chatting session, we had the impression that the chatting sessions in both experimental conditions can be classified as poor information sharing sessions. Most of the topics of the conversation were meant just to select the game interventions to solve the game events. Player conversations to elaborate together the information derived from the indicators or other game information resources as well as exchanging an understanding and knowledge of the problem being solved and the event, were rare. Something that could explain this conversation behaviour is the effect of time pressure in the experiment because the environment of the game was based on a forced time pace. Also there was lack of real interactivity, lack of instructional support, and flawed chat support in the KM Game environment.

What was said about the playing activities was also supported by the results of the interviews. The two players from each condition also did not confirm that they became more knowledgeable after playing the game. It is not too far fetched to assume that instead of learning KM the players were just playing and navigating the game for pleasure or simply because they volunteered and felt obliged to fill the time available.

Another minor remark is about the implementation of the chat tool, implementing interlaced windows in the interface is likely to create switching attention problems. Because in the KM Game system there were no other chat tools, the focus on the chat window became crucial to maintain communication. While dealing with other windows, this window switch is rather confusing. We have to take this into account for designing the real KM Quest system.

This study was explorative, there were no specific hypotheses that should be tested and the learning environment used was not the targeted one. The findings provide clues for improving the system and conducting future studies.

The last goal for this study was to investigate the suitability of the measurement strategies and instruments that can be used in the next studies. The strategy to measure the players' background information and ability to comprehend the chart can be re-used. The information will be useful to see if the experimental groups are equal in this respect.

This leads to the research approach for the next studies shown in Figure 4-9:

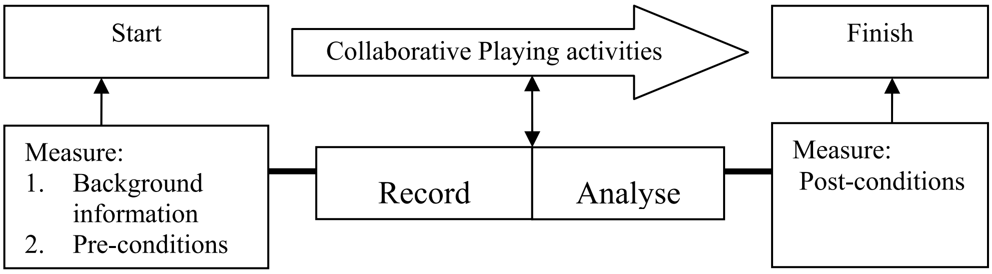


Figure 4-9. Research methodology and measurement strategies.

Figure 4-9 shows that pre and post-test experiments will be used, and the activities and communication during the playing session are recorded and analysed based on our group-decision making and problem solving model, to observe the use of information derived from the interpretation of the game indicators. When the players finish the game session, a post measurement session is conducted to measure the learning outcomes and an evaluation of the group decision making in the game. Thus the studies conducted in this dissertation permit the observation of the effects of the design in pre-, during, and post-conditions.

The measurement tools that we used in this study can be re-used. The TOGS+ and the filling form to obtain players' background information can be used in the beginning of the data collection – prior to the playing session. The players' decision making satisfaction questionnaire can be used at the end of the playing session to measure user's satisfaction with the group decision making process during the playing process. The log file recording used in this study proved to be insightful, although only providing the frequency of the accessed web pages. Of course the data from the recording facilities can not be analysed independently, we use this data to have a general preview of behavioural tendencies or preferences in the playing process that might give a clue to the overall analysis. Nevertheless, the challenge in this measurement methodology is on how to analyse, in an objective way, the communication process during the playing session and the collaborative playing activities of the players in group decision making in solving the KM problem.

In the next two chapters, two experimental studies will be presented to investigate the main research question.

5 Study 1: Effects of numerical information visualisation on the effectiveness of the group decision making process and learning outcomes

5.1 Introduction

In general, the theoretical framework states that learning KM collaboratively is contextualised by the group decision making process to solve KM problems during playing with KM Quest. Despite the cost-effectiveness of the text-based chatting tools to mediate the communication process in the group decision making process, it is thought to have negative effects on the overall process of decision making. The support of spatial numerical representations – the charts and the schematic map, is predicted to create better text-based communication processes during the decision making process than a symbolic numerical representation – the numerical table. As a result of the better group decision making process, we expect that the players will be more satisfied with the decision making process, and the learning outcomes will be better. With this statement we basically suggest that there are close relationships between the visualisation representations of the numerical information of the game indicators, the group decision making process and the embedded communication processes, the participant's satisfaction with the decision process, and the learning outcomes.

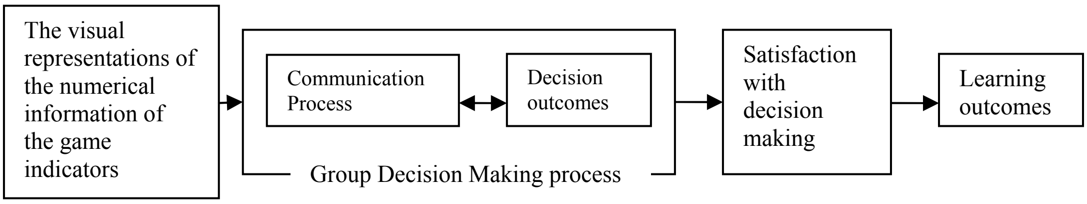


Figure 5-1. The research framework.

Figure 5-1 shows the outline of the theoretical framework. Essentially, as shown in the above figure, the group decision making process is defined as a collaborative process that consists of the communication process to carry out the subtasks of making decisions (see Figure 2-3) to produce the decision outcomes. These two aspects, communication process and decision outcomes, are closely intertwined and occur iteratively in the playing process. The intention of playing is to collaboratively carry out the sub-tasks of making decisions to solve KM problems and learn the consequences of the decisions. By closely understanding these two aspects of the decision making process, and combine it with the participants' satisfaction with the decision making process and the learning outcomes, we can observe whether the visual representations of the numerical information of the game indicators have supportive effects.

In the previous chapter, some characteristics of the communication process, the quantity of the decision outcomes, and the participants' satisfaction with the group decision making process have been preliminary investigated. The results of this study showed limited effects of the visualisation representations on these aspects. It was most likely caused by some technical and methodological shortcomings when conducting the preliminary study, such as the unavailability of the real KM Quest system and lack of insight about how players would integrate the numerical information derived from the visual representations of the game indicators and other information available in the game environment. Moreover, the preliminary study was also not able to investigate the learning outcomes after playing the game. Thus, it was not possible to link the support characteristics of the visual representation to the decision making process, players' satisfaction, and learning outcomes as shown in Figure 5-1.

In this chapter we will describe an experiment that is designed to provide evidence concerning hypotheses than can be derived from the theoretical framework.

5.2 General considerations

In this dissertation, the central process of group decision making is the communication process. In this process, the participants get involved collaboratively by means of exchanging text-based messages. While exchanging the text-based messages, they try to understand the messages and relate this information with their individual understanding or other sources of information. The whole process of exchanging text-based messages is a process of sharing information to achieve the main goal of the group decision making process – solving KM problems. The function of the visual representation of the numerical information in the game indicators for this process is crucial, because it acts as the source of objective and relevant information about the state of the world (the company they have to manage) in which participants have to solve the problem.

Using the above rationale, the different types of visual representations of the numerical information of the game indicator are assumed to directly influence the individual understanding of this information and then influence the entire communication process. From our perspective, the most important elements of the communication process during decision making are the information exchange sessions that reflect collaborative efforts to solve the problem.

The different types of visual representations of the numerical information of the game indicators and the numerical table are predicted to lead to differences in the way the players exchange the information to achieve a meaningful communication process in the group decision making process. Thus, the nature of the visual representations of the numerical information of the game indicators will influence the effectiveness of the information exchange sessions in the communication process. The more supportive these visual representations are, the more effective the information exchange sessions in the communication process in the group decision making will be.

The effectiveness of the information exchange sessions in the communication process is defined in four aspects: (1) the players' participation level of information exchange; (2) the profile of the group decision making phases during the communication process; (3) the occurrence of numerical information exchange sharing sessions in the decision making phases; and (4) the type of numerical information exchanged. Below each of these aspects is elaborated.

The players' participation level of information exchange is the first aspect to characterise the information exchange. In this aspect, the participation level of the players is measured by the average number of chat lines exchanged and the length of the chat message. It shows generally the communication process in terms of the intensity of exchanging the text-based messages.

The profile of the group decision making phases is the second aspect to characterise the information exchange. This profile is based on the model of the communication processes in the group decision making process (depicted in Figure 2-2 and Figure 2-3). The assumption is that these phases will be more effective, in terms of being more elaborately addressed during the communication process, when the information exchanged among players is more equally distributed in each phase. We expect that the distribution profile of communications over the group decision making phases will be balanced and not skewed for one particular phase. A skewed distribution may occur for instance when the players will just elaborate their idea collaboratively and fail to produce decision outcomes, or the players will just concentrate on selecting the interventions and forget to elaborate their idea collaboratively. Basically, we assumed that the balanced distribution over the decision making phases will be due to the information sharing session that means to exchange the information taken from the interpretation of numerical information in the visualisation of the game indicators.

The occurrence of the numerical information exchange sharing sessions in the decision making phases is the third aspect to characterise the information exchange. In this aspect, we expect that (1) in the "intelligence" phase of decision making, players will exchange information taken from the interpretation of the game indicators in trying to understand the relationship between the state of the game indicators and the problem to be solved; (2) in the "design" phase, players will share the information taken from the interpretation of the game indicators to exchange information in trying to obtain more information about the problem being solved and develop their ideas to solve the problem; (3) in the "choice" phase, players will share the information taken from the interpretation of the game indicators to exchange it in trying to evaluate their temporary decision outcomes and select the decision alternatives – the game interventions; (4) in the "feedback" loop, people will share the information taken from the interpretation of the game indicator to exchange the information in evaluating the past decisions.

The type of numerical information exchanged is the last aspect to characterise the information exchange. We expect the occurrence of the numerical information exchange sharing session to be characterised by a number of high quality types of sharing numerical information. What we mean with high quality types of sharing numerical information is sharing deep cognitive numerical interpretations, such as pattern detection or trend analysis, interpreting the tendency of a numerical pattern, and integrating and associating the numerical information with other types of information than in the numerical information.

These four aspects are believed to characterise the effectiveness of information exchange sessions in a text-based communication process.

From our point of view on the process of decision making, the effectiveness of the information exchange in the communication process will further influence the intermediate outcomes of the communication process in the playing process. The intermediate outcomes of the communication process are defined as the number of problems solved, the use of time, and use of the game budget. Basically, the intermediate outcomes of the communication process indicate the quality of the communication process in the decision making process from a different perspective than the above four aspects.

The end goal of the communication process in the decision making process is clearly to produce better decision outcomes. A better decision outcome can be defined quantitatively and qualitatively. However, the quality of decision outcomes is not easy to investigate in this study, particularly in the KM Quest setting, because there is no single best way to play the game. Thus a standard against which the quality of the decisions can be measured is lacking. Besides, the quality of the decisions is not the focus of this study, because our research interest is mainly on the process of communication in decision making and the learning outcomes afterward. It is more important to know the effectiveness of the communication process in the decision making process, the quality of intermediate outcomes of the decision making, and the quantity of the decision making outcomes. The quantity of the decision making outcomes will be indicated by the number of decision outcomes produced at the end of the communication process. We believe that adding the quantity of the decision outcomes, will complete our investigation of the group decision making process as a collaborative communication process (see Figure 5-1).

In our research framework, we stated that the group decision making process should also be assessed not only by the communication process but also by the satisfaction of the participants with the entire process of decision making. The consequence of the effectiveness of the entire communication process, the quality of intermediate outcomes of the communication process in the decision making process, and the quantity of the decision outcomes will influence the satisfaction of the participants with the group decision making. Following this rationale, the effects the types of visual representations of the numerical information of the game indicator are predicted to finally influence the learning outcomes at the end of the playing process.

5.3 Goal of the study

As can be derived from the previous sections, this study was conducted to compare the effects of the visual representations of the numerical information of the game indicators on group communication processes, intermediate outcomes of the communication process, the decision outcomes, the participants' satisfaction with the decision making process, and the learning outcomes. The comparison will be straightforward between teams that play with the KM Quest system that either have: (1) visualisation of the game indicators by means of the charts and the schematic map, the numerical table is not available; (2) the visualisation of the game indicators by means of only the numerical tables, the charts and the schematic map are not available. To achieve this, the learning environment must be modified to realise the different visual representations.

Although we explicitly predict that the spatial numerical representation, depicted by the charts and schematic map, will influence more positively the communication process, intermediate outcomes of the communication process, decision outcomes, participants' satisfaction, and the learning outcomes than the symbolic numerical information, depicted by the numerical table, we also think that the combination of both visual representations will provide the best support. The combination of the charts-schematic map and the numerical tables as implemented in the real KM Quest environment, theoretically is predicted to support the entire process of group decision making best, because it offers the widest range of numerical information resources that could be needed during the decision making process. The goal of designing information visualisation is to achieve a meaningful playing process with the combination of the charts, the schematic map, and the numerical tables because it provides both spatial and numerical information of the game indicators. Therefore, playing with the combination of the charts, the schematic map, and the numerical tables will lead to a better process of group decision making than with the charts and schematic map only, or the numerical tables only. However, one should realise that this might not necessarily be true in reality. Having more visual numerical information representations available can also confuse the players and add a new task to their decision making: deciding about what and where to look for information. This may take time and slow down the decision making process, resulting in more time needed to reach a decision and/or de-motivating the playing process.

The previous paragraph suggests us to create an additional comparison besides the two mentioned earlier, namely: visualisation of the game indicators by means of both the charts and schematic map, and the numerical tables. To achieve this, the original learning environment is used.

In the next section, predictions about the aspects of the group decision making process, the participants' satisfaction, and the learning outcomes are elaborated.

5.4 Predictions

First, it is predicted that teams, who are supported with a complete set of numerical information visual representations – the charts, the schematic map, and the numerical table, will communicate more effectively in the group decision making process, produce better quality of intermediate outcomes of the communication process, deliver a larger number of decision outcomes, are more satisfied with the group decision making process, and attain more positive learning outcomes than those who are supported with either the charts and schematic map only or the numerical tables only.

Second, the teams, who are supported with the spatial numerical information visual representations only - the charts and the schematic map, will communicate more effectively in the group decision making process, produce better intermediate outcomes of the communication process, a larger number of decision outcomes, are more satisfied with the group decision making process, and attain more positive learning outcomes than those who are supported with the symbolic numerical information only as presented by numerical tables.

Finally, the teams, who are supported with the symbolical numerical information representations only - the numerical table, will communicate least effectively in the group decision making process, produce the worst intermediate outcomes of the communication process, the lowest number of decision outcomes, are least satisfied with the group decision making process, and attain the least positive learning outcomes.

More specifically, the following hypotheses are tested in this study:

1. The charts and schematic map will support the players to produce more effective communication processes than the numerical table. The combination of the charts, schematic map, and numerical table will support the players to produce the most effective communication processes.
    a. The charts and schematic map will lead to a higher level of information exchange participation in terms of *the number of message lines exchanged* and *the length of the messages* than the numerical table only. However the combination of the charts, schematic map, and the numerical table will produce the highest level of information exchange participation compared with the other two representations;
    b. The charts and schematic map will produce a more balanced profile of the communication processes in the group decision making phases, which will be indicated by an equal *proportion of the communication processes occurring in the intelligence, design, choice, phases and the feedback loop of the decision making process*, than when having the numerical table only. However, the combination of the charts, the schematic map, and the numerical table, will produce the most balanced profile of communication processes over the group decision making phases;
    c. The charts and schematic map will produce a higher *occurrence of the numerical information exchange sharing sessions in the decision making phases: intelligence, design, choice, and feedback loop*, than the numerical table. However, the combination of the charts, the schematic map, and the numerical table, will show the highest occurrence of the numerical information exchange sharing sessions in the decision making phases than with the other two representations;
    d. The charts and schematic map will produce *a higher number of sharing deeper cognitive numerical interpretations indicated by numerical pattern detection or trend analysis*, *the interpretation of patterns of numerical information into a subjective evaluation, integrating and associating the numerical information with other types of information* than the numerical table only. However, the combination of the charts, the schematic map and the numerical table will show the highest number of sharing deeper cognitive numerical interpretations than the other two representations.

2. The charts and the schematic map will support the players to produce a better quality of intermediate outcomes of communication processes, which will be indicated with a higher *number of game events solved*, less *time needed for solving a problem in each game quarter*, and less *game budget used to solve the game events*, than the numerical table only. The combination of the charts, the schematic map, and the numerical table will support the players to produce the best quality of intermediate outcomes of the communication process than with the other two representations.
3. The charts and the schematic map will support the players to produce more decision outcomes which will be indicated by a larger *number of game interventions submitted*, than the numerical table only. The combination of the charts, the schematic map, and the numerical table will support the players to produce the most decision outcomes compared to the other two representations.
4. The charts and the schematic map will create more *satisfaction with the decision making process* than the numerical table only. The combination of the charts, the schematic map, and the numerical table will create the most satisfaction with the decision making process.
5. The charts and schematic map will support the players to attain more positive *learning outcomes* than the numerical tables only. The combination of numerical tables, charts, and diagrams, will support the players to attain the most positive learning outcomes.

5.5 Design of the study

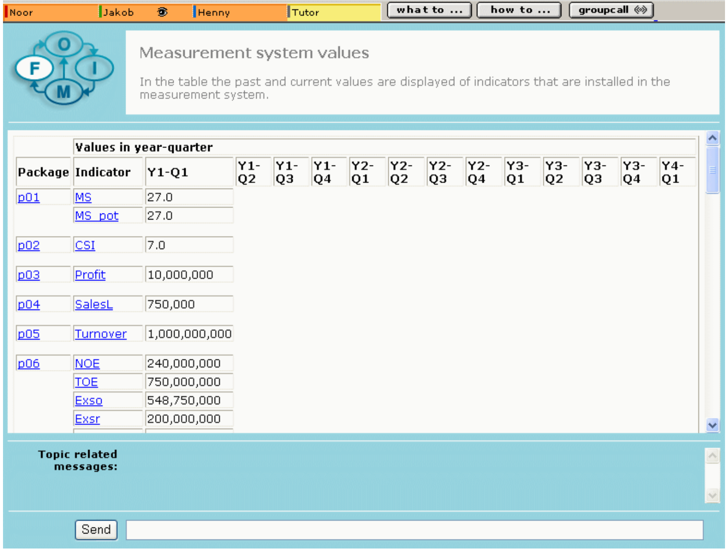
To investigate the predictions, the study follows the outline as presented in Section 4.4, an experiment with pre- and post-test measurements using three independent experimental groups. The communication processes and the decision outcomes were also recorded and later analysed. With this experimental design, controlled measurement to observe the effect of the visual representation on the group communication processes, the intermediate outcomes of the communication process in the decision making subtasks/phases, the number of decision outcomes, participants' satisfaction, and the learning outcomes is realised.

5.5.1 Conditions

We formed nine teams which consist of three players each. The teams were randomly assigned to one of the following experimental conditions:

1. Playing with the support of the charts and the schematic map (K_Map, see section 3.2.2.3) (C condition).
2. Playing with the support of the numerical table (T condition).
3. Playing with the support of combination of the charts and the schematic map, and the numerical table (TC condition).

The game environment for each experimental condition was customised. This means that the game environment for the C condition did not display symbolic numerical information in numerical tables at all. At the opposite, the game environment for T condition did not provide any visual spatial numerical information. The TC condition was exactly as the original version of KM Quest; it displayed both symbolic numerical tables and visual spatial numerical information (charts and schematic map). Below (Figure 5-2, Figure 5-3, and Figure 5-4) show the implementation of the information visualisation in the KM Quest system.



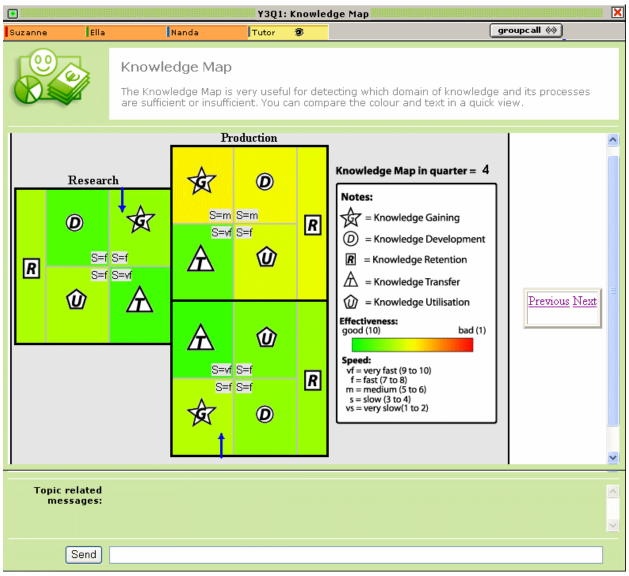
Measurement system values

In the table the past and current values are displayed of indicators that are installed in the measurement system.

	Values in year-quarter													
Package	Indicator	Y1-Q1	Y1-Q2	Y1-Q3	Y1-Q4	Y2-Q1	Y2-Q2	Y2-Q3	Y2-Q4	Y3-Q1	Y3-Q2	Y3-Q3	Y3-Q4	Y4-Q1
p01	MS	27.0												
	MS_pot	27.0												
p02	CSI	7.0												
p03	Profit	10,000,000												
p04	SalesL	750,000												
p05	Turnover	1,000,000,000												
p06	NOE	240,000,000												
	TOE	750,000,000												
	Exso	548,750,000												
	Exsr	200,000,000												

Figure 5-2. The numerical table displaying the game indicators.

In Figure 5-2 above, all values from the business model are presented in tabular form. As the number of indicators is large, quite some vertical scrolling is necessary and if the number of quarters increases during playing, also horizontal scrolling is necessary. As most of the information cannot be seen at a glance, finding, interpreting and discussing the numerical information is theoretically considered to be complex and hard to be done comprehensively. The T condition had only this type of table available.



Knowledge Map

The Knowledge Map is very useful for detecting which domain of knowledge and its processes are sufficient or insufficient. You can compare the colour and text in a quick view.

Knowledge Map in quarter = 4

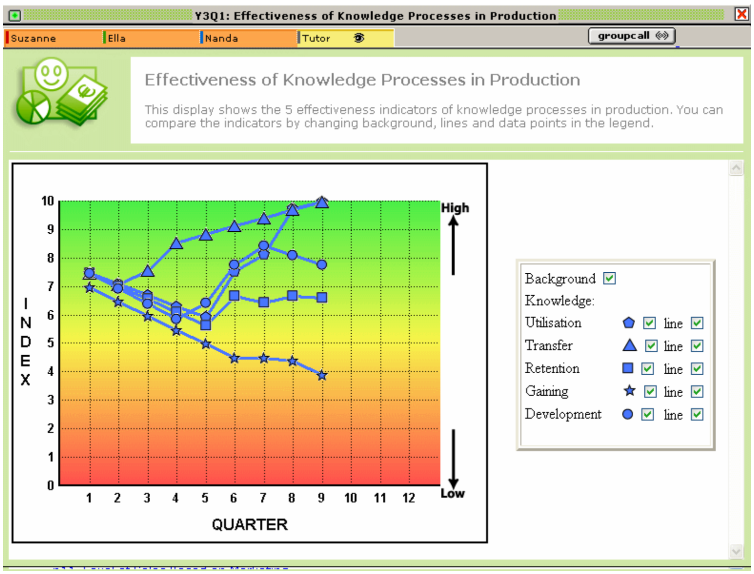
Notes:
G = Knowledge Gaining
D = Knowledge Development
R = Knowledge Retention
T = Knowledge Transfer
U = Knowledge Utilisation

Effectiveness:
good (10) bad (1)

Speed:
vf = very fast (9 to 10)
f = fast (7 to 8)
m = medium (5 to 6)
s = slow (3 to 4)
vs = very slow(1 to 2)

Figure 5-3. The schematic map visualisation of knowledge process indicators (K_Map).

Figure 5-3 shows an example of the schematic map representation, the knowledge processes indicators: the knowledge map (K_Map). This map shows the global state of 15 indicators using a colour coding (for more details see section 3.2.3.2). By clicking on the “Previous” or “Next” button (the time shifter button) the learner can see the map of the previous quarter, permitting a quick visual comparison of the game indicator values by using the colour coding.



Effectiveness of Knowledge Processes in Production

This display shows the 5 effectiveness indicators of knowledge processes in production. You can compare the indicators by changing background, lines and data points in the legend.

Background ☑
Knowledge:
Utilisation ⬟ ☑ line ☑
Transfer ▲ ☑ line ☑
Retention ■ ☑ line ☑
Gaining ★ ☑ line ☑
Development ● ☑ line ☑

Figure 5-4. An example of the charts in visualising knowledge process indicators.

Figure 5-4 shows an example of a chart in displaying the knowledge processes game indicators. In this chart several indicators are combined with a trend line and colour coding. Learners can switch off and on the displayed indicators by toggling the symbols displayed in the right hand rectangle (for more details, see section 3.2). Figure 5-3 and Figure 5-4 are accessible through a list of visualisation packages from which they can choose for displaying the game indicators. The teams in the C condition had only charts and diagrams, like the ones in Figure 5-3 and Figure 5-4, while the teams in the TC condition were provided with the charts, schematic map, and numerical table (Figure 5-2 to Figure 5-4).

5.5.2 Participants

This study was done independently from the one presented in the previous chapter. We recruited new players for this study. One month before the data collection was done, an advertisement for a one-day free of charge course of Knowledge Management was published to recruit participants. Twenty-seven international students from the Master of Science programmes Faculty of Educational Science and Technology of the University of Twente were registered to participate on a voluntary basis. We assumed that, again, these participants could be seen as prototypical beginners or novices concerning learning knowledge management. Out of these participants, we formed nine gaming teams. The students were assigned equally to the teams based on their education specialisation area. The teams were then randomly assigned to one of the experimental conditions.

Each participant received a financial reward which was given as a gift check with nominal value of 15 euro after finishing the experimental session.

5.5.3 Instruments

5.5.3.1 Laboratory settings and its computer facilities

The experimental sessions were held in the same room and facilities as in the preliminary study (see Chapter 4), the faculty's computer laboratory. We also made use of the same room setting and sitting positions. Each team member was located separately to prevent visual and auditory communication. Because of this room setting, we expect players not to be able to locate other team members in the laboratory room, to make sure that they could communicate using the text-based chat system only.

The hardware configuration of the computer was still the same: Pentium II 233 MHz processor, 128 MB RAM, and 17" SVGA colour display. However this time we used the Microsoft Internet Explorer^{TM} web browser version 6.0.

5.5.3.2 Learning environment: KM Quest version 2.0a

In order to make the results comparable, all teams started the game with the same initial values of the indicators and all teams had to handle the same events.

This experiment was done using the original KM Quest system version 2.0a, which has been modified to trigger nine pre-defined game events in ten game quarters. The events played for this study are shown in their order of occurrence in Table 5-1.

Table 5-1. The list of game event in the study.

Quarter	Keywords	Type
1 (trial)	Decreasing number of chemistry students graduations	External Threat
2	The European Union has announced for their next round of stimulating innovative Research and Development programs, a 100 Million EURO program for the environment friendly removal of building debris, which allows for re-use of old materials. In particular recycling of painted wood and polyester is a key research area.	Opportunity
3	Baro Corp has brought on the market an abrasive that allows dry sanding without causing an excessive dust. It has teamed up with a company selling sanding machines to deliver this abrasive in the same package with the machine.	External Threat
4	Gluco has developed a new production line for just-in-time delivery of products. The management board of Gluco has great expectations of this new development.	External Threat
5	Gluco has bought the company STIK, which has a strong position in industrial glues. It intends to expand the Research and Development department in STIK in order to strengthen its position in Do-it-yourself (DIY) household glues.	External Threat
6	An explosion occurred in a plant delivering packing materials for chemical reactive substances.	Internal Threat
7	To produce tiling adhesives Coltec relies on a natural product that is produced by rubber trees. Due to deforestation worldwide the number of rubber trees will decline significantly in the coming 5 years.	External Threat
8	The research unit of AMV Chemical Corporation, a competitor of Coltec on the Middle East market left the company and started a new company “Creative century”. The leader of Creative century stated that such a step was the result of disagreements concerning company development between a group of researchers and the managing board of AMV Chemical Corporation.	External Threat and opportunity
9	“New Resins” has announced the launch of the new Metalux 7654SS21/7890SS10 resin, developed exclusively for use in the production of decorative glass and sings.	External Threat
10 (end)	End of game (No event)	

These game events were selected because they do not depend for their triggering on specific not a priori predictable states, resulting from the combined effects of events and interventions by the players, of the business model. All of them are relevant to learn KM. This selection is intended to provide an attractive and challenging playing context, because the problems vary not only by threatening the condition of the business internally and externally, but also provides opportunities to grasp. We assumed that a novice player or a beginner learner in KM is more familiar with this selection and is challenged to translate both types of threats and the opportunities into KM problems to be solved.

The KM Quest system is fully implemented in the internet environment. The communication process among players uses the text-based chatting tool and the playing process is supported by the instructional tools (see section 3.1).

5.5.4 Measurement and observation instruments

The measurement and observation instruments are categorised according to the experimental design phases: before, during, and after playing.

5.5.4.1 Before playing

Background information of the players

In the same way as in the previous chapter, the background information about the players that we need to include in the analysis of this study is information about age, education, and gender; and also their ability to construct and interpret graphical charts in general. To obtain the information needed we used the same instruments: (1) a web filling form that records player's background information; and (2) a paper and pencil pre-test session of the TOGS+ (see chapter 4). The TOGS+ was delivered in 30 minutes.

Measuring KM prior knowledge

A paper and pencil pre-test of KM knowledge (Christoph, Leemkuil, Ootes, Shostak, & Monceaux, 2003) was administered to measure a base-line of KM knowledge. This test consists of two sections: the first section is an essay test to measure general KM knowledge which consists of two questions about the definitions of KM and understanding about conceptual models of KM; the second section has three questions in a case-based essay test to measure KM strategic knowledge that is related to the KM problem-solving model that is part of KM Quest (see Figure 3-3 and Figure 3-4). This case-based section has a similar business case as the one used in KM Quest, but uses a different type of business, a travel agent company. To test the problem solving skills, the players were asked to solve three events. This test was administrated for the maximum duration of 60 minutes.

5.5.4.2 During playing

Log files

Almost all players' interactions and communications are recorded on the server during the playing sessions. The recording facility of KM Quest produces several log files. From these log files, first, we can extract relevant information to verify our predictions about the intermediate outcomes of the communication process such as the time each team spent in each game quarter, the use of the game budget, and the number of events solved.

Secondly, from the log files we can extract relevant information about the number of game interventions submitted. Finally, from the log file we can extract data about the chatting sessions and other players' behaviours that are related with accessing certain types of visual representations of game indicators and decision making and communication processes. The chatting sessions log files were used to find the average number of message lines exchanged and the average number of words used in each message line (see Jones, 1997).

5.5.4.3 After playing

Players' satisfaction with the group decision making process

We used the same questionnaire as in the preliminary study, an adapted version of the Group Decision Making Satisfactory Questionnaire from Brigg and Vreede (1997). See previous chapter for detailed information. There is no time limit to finish this questionnaire; however the players were encouraged to answer questions with their first ideas about the overall group decision making session in mind.

Measuring the KM learning outcomes

After playing the game, the measurement of KM learning outcomes was done with a parallel version of the KM knowledge test (Christoph et al., 2003). This version uses exactly the same questions as in the first section of the KM knowledge pre-test and the same case description, but players must now solve three other events. This post-test was administered in the same time span as the pre-test.

5.6 Procedures

A complete KM Quest online training module was launched in the faculty's computer network three days before the experimental sessions. To access and perform the training module, each player received an individual user name and password access code via e-mail. They were asked to follow the training module at their own pace at least once before they come to the experimental session. The training module was designed based on the real playing situation but without the collaboration aspect. Each player can perform an individual training session.

The experimental sessions were held in the Faculty's laboratory for one full day (about 7 hours totally). On this day, the players were asked to enter the computer laboratory one by one. They received a sitting location code in the room and were asked to sit according to this experimental room setting. Each member of a team was located separately and informed to communicate only by the communication tools provided by the game. Visual and auditory communication was not allowed during playing. They also received a personal "virtual" identity before playing and were asked to hide their original identity during the game. The purpose of this is to reproduce the condition of geographical dispersion, that creates a communication atmosphere that feels as if players do not know each other and have to communicate at a distance. This condition was also maintained during the lunch break by having separate lunch break locations.

The experiment started with a short introduction and followed immediately with the before playing measurement session. This measurement session consisted of the pre-test sessions of the KM knowledge test and TOGS+. These two sessions were given by the experimenter. Before starting the gaming session, players were informed that they would have to play ten game quarters or nine game events. They were guided and introduced to the real game environment in a trial session. In this session they were asked to solve the first game event together with the experimenter and become familiar with the system, including the chatting and voting tools. In the trial session, we emphasised the importance of gathering information from the game indicators and combining it with some other information available from the game system. The gaming session followed immediately when the players entered the second game event. The players were asked to solve the remaining eight game events carefully and collaboratively, and do the synchronous chatting without bothering about a time limit. They were not asked to solve all game events but they must deliberately discuss the problem presented in the game event and find the solution using the available game budget, 3,000,000 Euro for each team, in a cost-effective way. We designed this task in order to reduce the time pressure and also to prevent a competitive atmosphere among teams. This gaming session was interrupted by one lunch break and several coffee breaks. After playing for about 5 hours, the playing was stopped and the players were asked to do the after playing measurement session that consists of the KM knowledge post-test and the group decision making satisfaction questionnaire.

5.7 Hypotheses

The hypotheses presented in the earlier section of this chapter can be restated as follows:

- The *first hypothesis* concerns the effectiveness of the communication process. It is expected that the effectiveness of the communication process is TC > C > T. The effectiveness of the communication process will be measured by:
    - The level of information exchange participation in terms of *the average number of message lines exchanged* and *the average length of the messages* in each condition (TC > C > T);
    - The profile of the communication processes over the group decision making phases, in terms of *the proportion of the communication processes occurring in the intelligence, design, choice, phases and feedback loop* (see Figure 2-3) will be more equally distributed in TC > C > T ;
    - The occurrence of sharing the interpretation of numerical information in the group decision making phases, in terms of *a high proportion of sharing numerical information of the game indicators in the intelligence phase, design phase, choice phase, and feedback loop* in group decision making process, will be higher in TC > C > T;
    - The number of sharing deeper cognitive numerical interpretations, indicated by *the frequency of the numerical pattern detections or trend analysis*, *the frequency of the interpretation of patterns of the numerical information into subjective evaluations*, and *the frequency of integrating and associating the numerical information with other types of information,* will be TC > C > T.

- The *second hypothesis* concerns the quality of intermediate outcomes of the communication process, which will be better in TC > C >T. This will be indicated with:
    - The *number of game quarters played* (TC > C > T);
    - The *time used in each game quarter* (TC < C < T);
    - The *use of the game budget* (TC < C < T).
- The *third hypothesis* concerns the quantity of the decision outcomes which will be indicated by *a higher number of game interventions submitted* in TC > C > T;
- The *fourth hypothesis* predicts that the player's satisfaction with the group decision making, measured with the Group Decision Making satisfactory questionnaire, will be TC > C > T;
- The *fifth hypothesis* states that the learning outcomes, as measured by the *KM tests*, will be TC > C > T.

5.8 Results

Some data collected by the measurement instruments must be pre-processed to obtain objective assessments. Those are the data from the KM essay test and the coding of the communication sessions. Both are detailed below.

5.8.1 Data processing

All players' answers to the pre- and post-test of KM knowledge were scored according to the scoring criteria supplied by the original test constructor. This process was done by the experimenter. Twenty-two percent from the total answers in each experimental condition were given to a second coder. The consistency of the test scores between the experimenter and second coder was tested with the Pearson correlation. A strong correlation between two assessors was found (Pearson correlation r(132)=.97). This proves the reliability of the scoring.

The chatting sessions were first segmented according to the game quarters. The game quarter segmentations are the fixed episodes of the communication process in the group decision making process, because in each game quarter the problem that the players have to solve is different and new at every quarter. The episodes of the communication process during decision making occurs recursively until reaching the end of the game. With this segmentation we have a maximum of 9 communication observation opportunities per team (The maximum number of observation opportunities is 9 quarters multiplied by 9 teams is equal to a maximum of 81 episodes). For each communication observation we first applied a conversational content segmentation and next applied the coding scheme to categorise each segment. Below the coding scheme is further elaborated.

Coding schemes

The content of the chatting sessions is analysed based on the categorisation of the group decision making phases introduced in Chapter 2. For this purpose we developed a coding scheme. Besides classifying the communication processes into the decision making phases, the numerical information sharing episodes are also analysed based on a more detailed labelling. The coding scheme (see Table 5-2 below) was built by matching the model of group decision making (the first column) and the communication subtasks in these phases (the second column of Table 5-2, see also Figure 2-3) with the player's interaction components in the KM Quest system (the third column of Table 5-2, see also Figure 3-11) and some findings from the communication sessions from the explorative study in Chapter 4. This coding scheme also categorised the chatting content that is concerned with the use of the game budget, and other factors in selecting and using the game indicators, to provide a full overview of the overall communication profile of the group decision making process.

Table 5-2. Mapping of Decision making process and KM Quest elements.

Simon's problem-solving phases	Comm. Sub-tasks in decision making phases	Comm.task in KM Quest (CODE)	Definitions	Properties (optional)
INTELLIGENCE	• recognise problems	**Ev**	Discussion about the actual game event	
	• diagnose characteristic	**IndEv**	Linking game indicators to the actual game event	4
DESIGN	• obtain information	**Ind**	Single Indicator interpretation	1, 2, 3, 4.
		InInd	Multiple indicators interpretation	1, 2, 3, 4.
		GC	Graph Comprehension	1, 2, 3, 4.
		NC	Numerical Comprehension	1, 2, 3, 4.
	• develop ideas	**Foc**	Focussing conversation	
		Obj	Setting decision objectives	
CHOICE	• evaluate alternative	**Bud**	Budget conversation	
		IntBud	Selecting Interventions based on budget constraints	
	• selection	**Int**	Selecting of and negotiating about Interventions	
		IndInt	Selecting interventions based on particular values of indicator	1, 2, 3, 4.
		EvInt	Selecting interventions based on understanding of the event	
		IndIntEv	Selecting interventions based on inferences about indicators and events	4
IMPLEMENTATION	• implementation	**Plan**	Planning	
Feedback		**Eva**	Evaluation	
		EvFedB	Previous Event Feedback	
		IndFedB	Indicator Interpretation Feedback	1,2,3,4
Off task		**Soc**	Social conversation	
		GO	Game Orientation	
		TO	Technical Orientation	
		Cls	Closing	
		Ref	Reflections	

Notes: The properties are applied to the code if the number/visual comprehension process is relevant. The meaning of the properties is:

1. *Retrieving data (mentioning value/data only). For example: "the profit is… 9 million"*

2. *Recognising a pattern of data (mentioning/comparing min-max values, high-low values, distribution, tendency/global trends: going up or down, increasing or decreasing; and proportions: percentage, half, quarter, and one-third). For example.: "I saw the profit is going up or decrease"*
3. *Interpreting a tendency in numerical information (interpreting the pattern of the numerical information into subjective evaluation). For example: "we do have low profit…."*
4. *Integrating and inferring or associating and perceiving relationships between numerical information and other information resources. In most occasions, it predicts relationships between a game indicator, interventions, and/or an event. For example: "Our profit is going down but customer satisfaction index is going up" or "The company's database is crashed, that is why the customer satisfaction index is decreasing".*

The coding scheme is also designed to detect and categorise the episodes of sharing cognitive numerical interpretations in each phase of the group decision making communication process, by applying the optional sub-codes of the information sharing episodes in the decision making phases (the fifth column). These optional sub-codes represent evidence concerning the episodes of sharing cognitive numerical interpretations in four depth categories (see the notes section of Table 5-2). The six code categories in the third column *(IndEv*, *Ind, InInd, IndInt, IndIntEv IndFe),* can be made more detailed by applying the sub-codes from the fifth column, if the content of the log files is relevant. Not all code categories have an equal number of optional properties. Due to the complexity of the communication in the decision making phases, not all codes may be followed by all possibilities of optional sub-codes. Two complex codes in the third column (IndEv and IndIntEv) may appear in the communication session and follow by sharing the deepest cognitive interpretation (category 4 of the optional code) only. The other codes in the third column do not necessarily require players to only share the deepest cognitive interpretation.

A second rater was asked to independently code 15%, or minimal 50 segments, from the total number of segments (Neuendorf & Skalski, 2002; Reiss, 1985). Cohen's Kappa inter-rater agreement coefficient for C, T, and TC condition, yielded respectively .71, .70, and .81, meaning that there is an acceptable agreement between the first and the second rater. As a consequence the codes of the first coder are the data used in the analysis.

5.8.2 Background information of the players

5.8.2.1 Demographic information of the players

The demographic information of the players presented in this section was taken from the identification form that requests information about age, gender, educational background, and familiarity with internet chatting tools. This information was needed to see if there are variations that could influence the comparison between the experimental conditions.

Table 5-3. General summary of background of players.

Cond	N(n)	Mean Age (year; month)	s.d. Age (year; month)	Gender	Education
C	3(3)	28; 4	5; 1	8 ♀	9 BSc.
T	3(3)	26; 7	3; 1	6 ♀	9 BSc.
TC	3(3)	28; 7	3; 11	7 ♀	9 BSc.

Notes: ♀ = female participants; BSc.= Bachelor of Science Degree

Table 5-3 shows almost equal backgrounds for the players in each condition except in terms of age. We can see that the average age of the players in T condition is slightly younger than the other two conditions. Since the difference is not large, we do not think that the players in T condition will play differently compared to those in the other two conditions.

It is rather surprising that the advertisement of KM Quest attracted more female participants, because the percentage of the female students from the total target population is about 65%. We do not have an explanation for this phenomenon. As there is no reason to assume that females are either better or worse than males in learning KM through game playing, we do not have to worry about this skewed distribution in the sample, as long as the difference between the conditions are not too large.

Concerning familiarity with chatting tools, almost all players stated that they are very familiar with these. Only one person in the C and T condition reported that he/she had never used an internet chat facility before. The average time each player spends on chatting was about 5.5 hours/week for the C condition, 4.5 hours/week for the T condition, and 4 hours/week for the TC condition. There are some differences between the conditions, but as the number of hours spent is considerable in each condition, we do not expect this to influence the results.

5.8.2.2 Graphing construction and interpretation skills

The TOGS+ test was delivered to detect differences between players' general ability to construct and interpret graphical charts.

Table 5-4. Average test scores of TOGS+.

Cond.	N	M(s.d.)
C	9	24.1(4.7)
T	9	25.7(3.1)
TC	9	24.2(5.0)
Total	27	24.7(4.3)

Notes: max. score= 32 points

Table 5-4 indicates that there are no significant differences in TOGS+ average test scores between the experimental conditions. The Kruskal-Wallis test did not confirm significant differences of the TOGS+ scores between the experimental conditions (χ^2=.847, df=2, p=.655). We concluded that all players in each experimental condition have equal and high skills in constructing and interpreting graphs. Cronbach's Alpha of TOGS+ in this study is .75, which is satisfactory.

As we can see from above, there is no evidence for meaningful differences in the player's background profiles and their ability to construct and interpret graphical charts between the experimental conditions. Based on these we can conclude that the players in the three conditions are comparable.

In the next section, we investigate the hypothesis concerning the effectiveness of the communication process during group decision making.

5.8.3 Effectiveness of the communication process

There are five indicators to compare the effectiveness of the communication process: the level of information exchange participation, the profile of the communication processes over the group decision making phases, the occurrence of sharing the interpretation of numerical information, and the number of sharing deeper cognitive numerical interpretations. The next sections address each of these indicators.

The unit of analysis in this section is mostly the team. The analysis was done on the basis of the communication process in each team in the experimental conditions. The analysis done in this section is purely explorative. Due to the small number of observations in each condition, we are unable to test findings statistically. This creates a limitation that the testing of hypothesis is judged on the basis of the average values and the standard deviations. The drawback of this method is that due to the variance in the team's communication processes (the standard deviations of the scores are rather high), the conclusions drawn in this section have a limited value for generalisation.

5.8.3.1 The level of information exchange participation

On average, each team in the C, T, and TC condition exchanged about 438.7 (s.d.=48.17, N=3), 615.0(s.d.=302.26 N=3), and 605.7(s.d.=110.64, N=3) message lines during the playing process. We can see that the standard deviation of the average number of message lines in the T condition is very large. It indicates that the participation level of the teams in this condition varies strongly from team to team. This finding will also be found to dominate other observational results of the communication process of the teams in this condition. Within these average number of message lines exchanged, the average length of the message lines in term of the number of words in the C, T, TC conditions are, about 6.7(s.d.=1.60), 5.1(s.d.=.46), and 5.7(s.d.=.95) words.

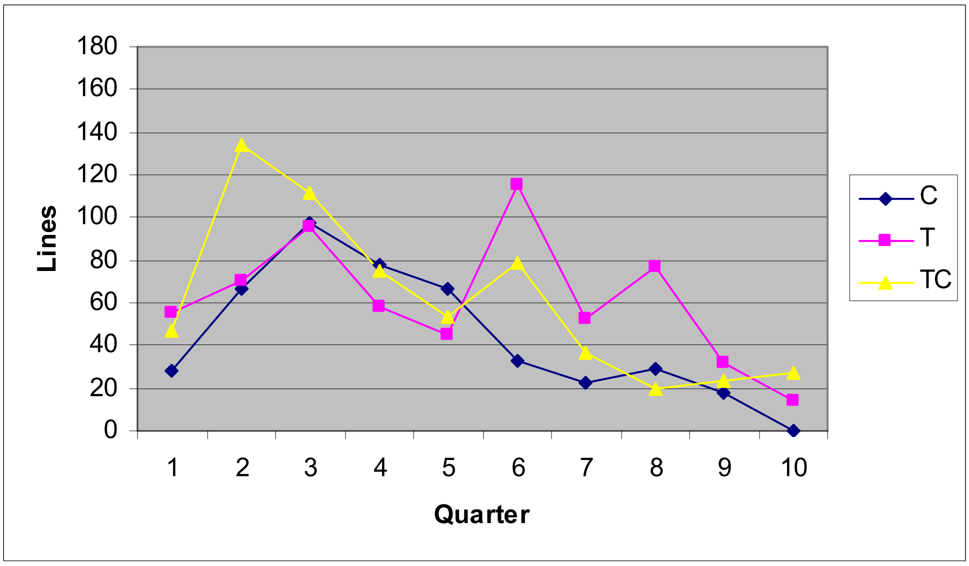


Figure 5-5. The chatting sessions profiles based on the average number of chat lines.

Figure 5-5 shows the fluctuation of the average number of chat message lines over all game quarters. With this figure, it is confirmed that the chatting sessions of the teams in the T condition are the most intense but fluctuate strongly over time. The tendency of the average number of chat message lines in the other two experimental conditions is more steadily declining than in the T condition. It is also shown in the T condition that the peak of the average number of message lines is in the game quarters 3, 6 and 8, requiring problem solving about an external threat, internal threat, and external threat-opportunity type of event. Whereas in the TC condition, the fluctuation in the average number of chat lines did appear only in quarters 2 and 6, and in the C condition in quarters 3 and only slightly in quarter 8. It seems that the fluctuations in the average number of chat lines exchanged is more marked in the T condition than in the other two conditions. It could indicate that the level of information exchange participation in the T condition is more marked due to the type of the event and possibly due to the interpretation of the numerical information which is more difficult and may lead to cognitive biases.

From the finding above, we could not confirm our prediction in the first part of the first hypothesis about the level of information exchange participation. We conclude that teams in the T condition participated in the communication process by exchanging on average the largest number of message lines during playing, but used the smallest average message line length. This finding is the opposite of findings for the teams in the C condition who exchanged on average the least message lines, but with the longest average line length. The teams in the TC condition exchanged on average an intermediate average number of message lines and also an intermediate average line length.

5.8.3.2 The profile of the communication processes over the group decision making phases

The profile of the communication processes indicates the proportional distribution of the communication processes over the group decision making phases in the overall playing process. This profile is constructed based on the proportion of the occurrence of the communication processes in each decision making phase in the total playing processes in each experimental condition. As there are 9 teams each going through a maximum of 9 game quarters, and each quarter can be seen as a new decision making process, the sample of decision making processes investigated is a maximum of 81 episodes. However, we noticed that not all teams reached the end of the game during the data collection session. The average number of game quarters played in each condition is presented in section 5.8.4.

From the overall communication process during playing, the average number of segments containing chatting contents that could be classified into the phases of the decision making process of the teams in the C, T, and TC conditions, are respectively 48.0(s.d.=14.8, N=3), 60.3(s.d.=19.6, N=3), and 49.7(s.d.=14.2, N=3). Based on these segments, a proportion based profile of the distribution of communication processes over the decision making phases (see Figure 2-3) in the playing process is shown in Figure 5-6.

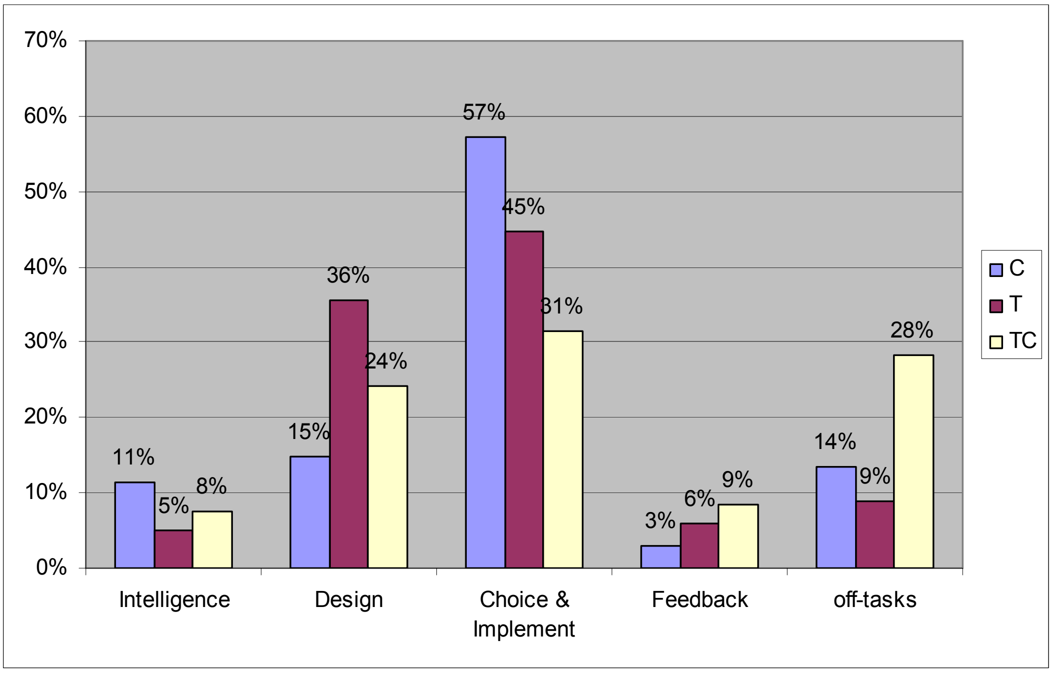


Figure 5-6. Proportional distribution of the communication processes over the decision making phases.

The prediction of a balanced profile of the communication processes over the decision making phases is defined based on the following proportion distribution criteria: the off-tasks communication process will be 10%; the intelligence, the design, and the choice and implement phases will be about 22.5%; the same prediction is applied to the feedback loop which will be about 22.5%. We formulate the definition of a balanced profile of the communication process over the decision making phases purely heuristic and intuitive because there is no theoretical reference that describes a norm for the profile. Our theoretical reference suggests that each of the decision making phase is equally important and should receive an equal part of the overall communication efforts.

Table 5-5. Differences between observed and expected values in the communication profiles.

	Intelligence			Design			Choice & Implement			Feedback			Off-task			∑D
	O	E	D	O	E	D	O	E	D	O	E	D	O	E	D	
C	11	22.5	11.5	15	22.5	7.5	57	22.5	34.5	3	22.5	19.5	14	10	4	77
T	5	22.5	17.5	36	22.5	13.5	45	22.5	22.5	6	22.5	16.5	9	10	1	71
TC	8	22.5	14.5	24	22.5	1.5	31	22.5	8.5	9	22.5	13.5	28	10	18	56

Notes: O= observed value (%); E= Expected value (%); D= the difference between observed and expected values; ∑D *= total of differences (%).*

From Figure 5-6 and Table 5-6 we can see that the profile of the communication processes in the TC condition is slightly close to our prediction but this condition has a very high proportion in the off-tasks communication process category. The profile of the communication processes in the T condition is also relatively close to our prediction compared to the profile of the communication processes in the C condition. Below we further elaborate the differences of the profile of the communication process in each experimental condition.

It can be seen from Figure 5-6 that on average the teams in the C condition did have the highest proportion in talking about decision alternatives and trying to implement them collaboratively ("Choice and Implement" phase contains 57% from all their segments). This means that the teams in the C condition on average focused more than half of their chatting sessions on making choices and trying to implement them. They devoted less chatting to developing their understanding of information and others ("Design" phase contains 15% from all their segments). Compared with the proportion of the "Choice and Implement" communication process category, we have the impression that the chatting sessions in the C condition were straightforward to choose and implement decisions only. In terms of investigating the game event, the teams in the C condition did have limited communication ("Intelligence" phase contains 11% from all their segments) but it is still the highest compared with the other two conditions. The chatting sessions in the C condition in providing feedback information to the group, the "feedback" loop, contains only 3% from all their segments. This is lower than expected and rather different from what was found in the other conditions.

A rather different profile is found for the teams in the T condition. For some reasons, the teams in this condition focused their chatting session less on making a choice and trying to implement the choice ("Choice and implement" phase contains 45% from all their segments) than the teams in C condition. The teams in the T condition also seem to elaborate their ideas more in the "Design" phase, 36% from all their segments, which is the highest of all conditions. For the communication process to provide feedback loops in the decision making process, the teams in the T condition focused slightly more on this than the teams in the C condition; although it is still rather low ("feedback" loop is 6% from all their segments). The focus of the chatting sessions on elaborating the problem in the team is also rather low ("intelligence" phase contains 5% from their segments).

An interesting aspect in the profile of the TC condition is the high proportion of off-tasks chatting topics ("off-tasks" category contains 28% from all their segments). This could be an indication that the possible confusing effect of having too much information available, mentioned in section 5.3, occurred. The feedback loop type of chatting sessions in this condition is the most dominant one compared with the other two conditions ("feedback" loop contains 9% from their overall segments), but is still rather low. In terms of developing ideas and obtaining more information, making choices and trying to implement the choices, the teams in this condition did not so dominantly focus their chatting sessions on them as in other two conditions ("design" and "choice and implement" phases contain respectively 24% and 31% of all their segments). The focus of the chatting session on recognising and diagnosing the characteristics of the problem is intermediate ("intelligence" phase contains 8% from all their segments) compared to other the two conditions.

The evidence shows that we could not confirm our prediction in the second part of the first hypothesis. We found that the teams in the TC condition had a more balanced profile of communication processes over decision making phases than in the other two conditions. In fact, the teams in the C condition were more concentrating on the decision phase to choose and implement decision outcomes than on the one to collect more information and elaborate their ideas compared to the T and TC conditions. In addition, the overall profile of communication processes of the teams in the TC is slightly comparable to the T condition except that the teams in the TC condition seem to have problems in their decision making. The decision making phases profile in the TC condition indicated that they focused more than 10% (our criteria) of their chatting sessions on the sub-task that does have nothing to do with decision making. We concluded that the teams in the TC condition had a more balance decision making phases profile than in the other two conditions and the teams in T condition had a rather better balance than in the C condition.

5.8.3.3 The occurrence of sharing the interpretation of numerical information

A detailed analysis of the content of the chatting sessions is carried out to find the episodes where players share the information taken from the game indicators in the group decision making phases which is the third indicator of the effectiveness of the communication processes. The result of this analysis is presented in Table 5-6.

Table 5-6. The average proportion of occurrence of the interpretation of numerical information in decision making phases.

			C (N=3)		T (N=3)		TC (N=3)	
Simon's problem-solving phases	**Comm. Sub-tasks in decision making phases**	**Comm.task in KM Quest (CODE)**	*M(s.d.)%*		*M(s.d.)%*		*M(s.d.)%*	
INTELLIGENCE	• recognise problems	Ev	9.7	(0.6)	3.1	(4.3)	5.5	(1.3)
	• diagnose characteristic	IndEv	$1.7^{(3)}$	(3.0)	$1.9^{(2)}$	(1.7)	**2.1**$^{(1)}$	(2.4)
DESIGN	• obtain information	Ind	$5.4^{(3)}$	(5.5)	**14.6**$^{(1)}$	(6.2)	$9.1^{(2)}$	(9.9)
		InInd	$1.8^{(3)}$	(1.8)	**6.0**$^{(1)}$	(6.0)	$4.3^{(2)}$	(3.8)
		GC	0.6	(1.0)	0.0	(0.0)	0.0	(0.0)
		NC	0.0	(0.0)	3.8	(2.3)	2.4	(2.3)
	• develop ideas	Foc	5.3	(5.2)	5.6	(4.2)	4.7	(0.2)
		Obj	1.8	(1.7)	5.6	(4.3)	3.7	(3.2)
CHOICE	• evaluate alternative	Bud	4.5	(2.4)	6.6	(2.7)	3.5	(1.4)
		IntBud	8.6	(1.5)	7.6	(2.1)	4.0	(1.4)
	• selection	Int	20.2	(10.5)	12.4	(6.9)	11.7	(5.7)
		IndInt	$8.9^{(3)}$	(9.6)	**13.2**$^{(1)}$	(5.4)	$9.3^{(2)}$	(8.1)
		EvInt	14.0	(7.5)	3.1	(1.8)	1.6	(1.4)
		IndIntEv	$1.2^{(2)}$	(1.0)	**1.3**$^{(1)}$	(2.2)	$0.5^{(3)}$	(0.9)
IMPLEMENT	• implementation	Plan	0.0	(0.0)	0.4	(0.7)	0.8	(1.4)
Feedback		Eva	1.8	(1.7)	1.3	(1.3)	4.5	(4.0)
		EvFedB	0.6	(1.0)	0.8	(1.4)	0.0	(0.0)
		IndFedB	$0.6^{(3)}$	(1.0)	$3.8^{(2)}$	(3.4)	**4.0**$^{(1)}$	(3.8)
Off task		Soc	0.0	(0.0)	0.8	(1.4)	6.2	(10.7)
		GO	5.1	(4.6)	2.2	(0.5)	8.9	(6.7)
		TO	7.6	(4.7)	4.6	(4.0)	9.8	(6.6)
		Cls	0.6	(1.0)	1.3	(1.3)	2.1	(0.5)
		Ref	0.0	(0.0)	0.0	(0.0)	1.3	(1.2)
		TOTAL	100% ≈ 48.0		100% ≈ 60.3		100% ≈ 49.7	

Notes: the values in this table present the percentage of the occurrence of codes in each decision making phase. The greyed rows are the occurrence of the interpretation of numerical information. ***(1)*** *= first rank; (2)= second rank; (3)= third rank.*

In the early phase of group decision making – the "intelligence" phase, the process of communication collaboration exchanges information taken from the game indicators that is related with recognising and diagnosing the characteristics of the problem being solved (*IndEv* category). It was found that all teams in the three experimental conditions did this almost equally infrequent (M_{Ccond}=1.7%, s.d.$_{\text{Ccond}}$=3.0%; M_{Tcond}=1.9%, s.d.$_{\text{Tcond}}$=1.7%; M_{TCcond}=2.1%, s.d.$_{\text{TCcond}}$=2.4%).

In the "design" phase, the communication process is expected to enhance the exchange of information from the game indicators in two ways: interpretation of single game indicators and interpretation of multiple indicators. It was found that the teams in the T condition shared information taken from the interpretation of a single indicator (*Ind* category) the most frequent (M_{Tcond}=14.6%, s.d.$_{\text{Tcond}}$=6.2%) compared with the other two conditions (M_{Ccond}=5.4%, s.d.$_{Ccond}$=5.5%; M_{TCcond}=9.1%, s.d.$_{TCcond}$=9.9%). As for sharing information taken from multiple game indicators (*InInd* category), the teams in the T condition did this also most frequent (M_{Tcond}=6.0%, s.d.$_{Tcond}$=6.0%, M_{Ccond}=1.8%, s.d.$_{Ccond}$=6.0%; M_{TCcond}=4.3%, s.d.$_{TCcond}$=3.8%).

In the “choice and implement” phase, where players communicate to elaborate the decision alternatives, sharing of the interpretation of game indicators is expected to occur as well. We found that the occurrence of sharing interpretations of game indicators in elaborating the game intervention selection (*IndInt* category) are most frequent for the teams in the T condition (M_{Tcond}=13.2%, s.d.$_{Tcond}$=5.4%, M_{Ccond}=8.9%, s.d.$_{Ccond}$=9.6%; M_{TCcond}=9.3%, s.d.$_{TCcond}$=8.1%). In the next category, where players try to combine the interpretation of the game indicators with the event in intervention selection (*IndIntEv* category), we found that all teams in this study communicated very rarely about this category (M_{Ccond}=1.2%, s.d.$_{Ccond}$=1.0%; M_{Tcond}=1.3%, s.d.$_{Tcond}$=2.2%; M_{TCcond}=.5%, s.d.$_{TCcond}$=.9%).

In exchanging the information taken from the game indicators to have a feedback loop about teams’ past decisions (*IndFedB* category), it was found that this is slightly more frequent in the teams in the TC condition (M_{TCcond}=4.0% s.d.$_{TCcond}$=3.8%) than in the team in the T condition (M_{Tcond}=3.8%, s.d.$_{Tcond}$=3.4%). In the teams in the C condition, this is extremely low (M_{Ccond}=.6%, s.d.$_{Ccond}$=1.0%).

From these findings we could not confirm our predictions in part three of the first hypothesis. We conclude that the proportion of information sharing episodes in “intelligence”, “design phase”, “choice”, and “feedback” loop phases that share numerical and visual information of game indicators in the T condition is the highest one. Comparing the proportion of the information sharing episodes between the C and TC condition, we found that the proportion of the numerical information sharing in the TC condition is higher than in the C condition.

Apart from the numerical information sharing sessions, we were also interested to observe the high proportion of the “off-tasks” episodes in the overall communication process of the TC condition. It was found that on average the teams exchanged a considerable number of different off-task topics such as game orientation (M_{GO}=8.9%, s.d.$_{GO}$=6.7%), technical orientation (M_{TO}=9.8%, s.d.$_{TO}$=6.6%), and social conversation (M_{Soc}=6.2%, s.d.$_{Soc}$=10.7%) in their chatting session. This finding indicates that the communication process during the group decision making was dominated by the orientation type of communication to play and understand the game system. This is likely an indication of difficulties with the playing process and in understanding the game environment, which could be due to the larger variety of information available.

5.8.3.4 The number of sharing deeper cognitive numerical interpretations

The fourth component of the effectiveness of the communication process is the average number of sharing of deeper cognitive interpretations. This is measured by applying the detailed codes in the fifth column of Table 5-2. The results are shown Table 5-7.

In Table 5-7, the codes from the decision making phases are based on the following categories, also mentioned below Table 5-2:

1. Retrieving and mentioning values from the game indicators;
2. Recognising a pattern of values of the game indicators, such as mentioning/comparing min-max values, high-low values, distribution, tendency/global trends;
3. Interpreting a tendency in the numerical information (interpreting the pattern of the numerical information into a subjective evaluation);
4. Integrating and inferring or associating and perceiving relationships between numerical information and other information resources.

In the fourth part of the first hypothesis we said that the frequency of the numerical pattern detections or trend analysis, the frequency of the interpretation of pattern of the numerical information into subjective evaluations, and the frequency of integrating multiple numerical information sources and integrating the numerical information sources with other types of information than in the numerical information will be TC > C > T. We can find these frequencies by observing the points (2) to (4) in the above categorisation. Point (1) is excluded from the hypothesis analysis because it does not reflect any cognitive numerical interpretation. Retrieving and mentioning values from the game indicators is just making a reference or an attempt to repeat the numerical information in communication processes. However in Table 5-7 we present all findings from this chat analysis because they might provide valuable observation data about how frequent players share their cognitive numerical interpretations in the communication process.

Table 5-7. Average number of sharing deeper cognitive numerical interpretations.

Labels	M(s.d., N=3) C	M(s.d., N=3) T	M(s.d., N=3) TC
IndFedB(1)	0.3 (0.6)	0.0 (0.0)	0.3 (0.6)
IndFedB(2)	0.3 (0.6)	**2.7 (2.5)**	**2.0 (3.5)**
IndFedB(3)	0.0 (0.0)	1.7 (2.9)	0.3 (0.6)
IndFedB(4)	0.0 (0.0)	0.7 (0.6)	0.0 (0.0)
IndEv(4)	0.0 (0.0)	0.3 (0.6)	0.3 (0.6)
Ind(1)	0.3 (0.6)	1.7 (1.2)	1.3 (1.5)
Ind(2)	**2.3 (3.2)**	**5.7 (5.0)**	**2.7 (3.1)**
Ind(3)	1.7 (2.1)	**6.7 (6.4)**	**3.7 (5.5)**
Ind(4)	0.7 (1.2)	1.3 (1.5)	0.3 (0.6)
InInd(1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
InInd(2)	0.0 (0.0)	1.3 (2.3)	1.7 (1.5)
InInd(3)	0.0 (0.0)	1.0 (1.7)	1.3 (1.5)
InInd(4)	1.0 (1.0)	**2.7 (1.5)**	1.3 (2.3)
GC(1)	0.0 (0.0)	n.a. n.a.	0.0 (0.0)
GC(2)	0.7 (1.2)	n.a. n.a.	0.0 (0.0)
GC(3)	0.0 (0.0)	n.a. n.a.	0.0 (0.0)
GC(4)	0.0 (0.0)	n.a. n.a.	0.0 (0.0)
NC(1)	n.a. n.a.	0.3 (0.6)	0.0 (0.0)
NC(2)	n.a. n.a.	1.0 (1.0)	0.3 (0.6)
NC(3)	n.a. n.a.	0.7 (0.6)	1.0 (1.0)
NC(4)	n.a. n.a.	0.0 (0.0)	0.0 (0.0)
IndInt(1)	0.0 (0.0)	0.0 (0.0)	0.7 (1.2)
IndInt(2)	0.7 (1.2)	0.7 (1.2)	0.0 (0.0)
IndInt(3)	0.3 (0.6)	0.3 (0.6)	1.0 (1.7)
IndInt(4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
IndIntEv(4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOTAL	**8.3 (7.6)**	**28.7 (19.7)**	**18.3 (19.3)**

Notes: the values are the average number of sharing cognitive numerical interpretations during the playing process. "n.a." = not available.

In Table 5-7, we can see that the T condition on average showed the highest number of sharing cognitive numerical interpretations derived from the game indicators (TOTAL: M_{Ccond}=8.3, s.d.$_{Ccond}$=7.6; M_{Tcond}=28.7, s.d.$_{Tcond}$=19.7; M_{TCcond}=18.3, s.d.$_{TCcond}$=19.3).

In the T condition, the teams shared cognitive numerical interpretations of the game indicators mostly in interpreting the meaning of values from a single game indicator according to their personal qualitative evaluation - *Ind(3)* category (M_{Tcond}=6.7, s.d.$_{Tcond}$=6.4 times). This process entails an interpretation of a range of values in the game indicators such as the interpretation of a certain index level value to an understanding of a "better" or "worse" level. Moreover, the teams in the T condition shared cognitive numerical interpretations of single game indicators in the form of recognising the pattern of values from the single game indicators such as "up or down" or "high-low" – the *Ind(2)* category (M_{Tcond}= 5.7, s.d.$_{Tcond}$=5.0). These two findings can also be found in the TC condition but they do differ in the number of episodes (*Ind(3)*: M_{TCcond}=3.7, s.d.$_{TCcond}$=5.5 times; *Ind(2)*: M_{TCcond}=2.7, s.d.$_{TCcond}$=3.1 times.

In the previous section, it was mentioned that "the feedback loop" type of codes in the T and TC conditions were almost equal. It was also found that the kind of interpretations that the teams shared in both conditions were almost of the same type (*IndFedB(2)*: M_{Tcond}= 2.7, s.d.$_{Tcond}$=2.5; M_{TCcond}=2.0, s.d.$_{TCcond}$=3.5) meaning that the teams in both conditions shared the interpretation of pattern of values of the game indicators in the feedback loop.

Generally, in terms of the average number of the sharing deeper cognitive numerical interpretations, we could not confirm our prediction in the fourth part of the first hypothesis. We concluded that the teams in the T condition obviously had a higher average number of sharing deeper cognitive numerical interpretations than the teams in the C condition. However, compared to the teams in the TC condition, the teams in the T condition on average did have a slightly lesser number of sharing deeper cognitive numerical interpretations. Nevertheless, we can also hardly find that either the teams in the T or TC conditions did share information based on a more deeper interpretation such as integrating and associating the numerical information with other types of information than in the numerical information (see the row of "*IndFedB(4)*", "*Ind(4)*", "*InInd(4)*", "*IndInt(4)*", and "*IndIntEv(4)*" in Table 5-7.

5.8.3.5 Additional observation on the way the teams accessed the numerical information

The results from the previous section raise the question what numerical information the players actually accessed. This can provide clues whether the numerical information shared in the communication process was indeed based on the visual representations of the game indicators. The data needed for this were extracted from the server's log file that provides the frequency of accessed game sections including the accessed the chart packages and the numerical table.

In Figure 5-7 we can observe that teams in the C condition were concentrating their activity on accessing the visualisation packages in the category of the organisational effectiveness variables, the upper most layer of the indicator structure in the BM model (see Figure 3-5) which is directly influenced by external events. It is rather unexpected that we found on average a very low frequency of accessing the knowledge map; it was nearly never used during playing activities.

The most unexpected finding can be seen in the frequency of accessing chart packages in the teams of the TC condition. It was found that, on average, frequency of accessing charts and K_Map packages was extremely low compared to the teams in the C condition (M_{TCcond}=13.3, s.d. $_{TCcond}$=14.5; M_{Ccond}=62.3, s.d. $_{Ccond}$=80.0; N=3). Although there is an indication that the teams in the TC conditions tried to access some chart packages, such as the knowledge related variables, most chart packages were infrequently accessed and the overall frequency is much lower than the one from the teams in the C condition.

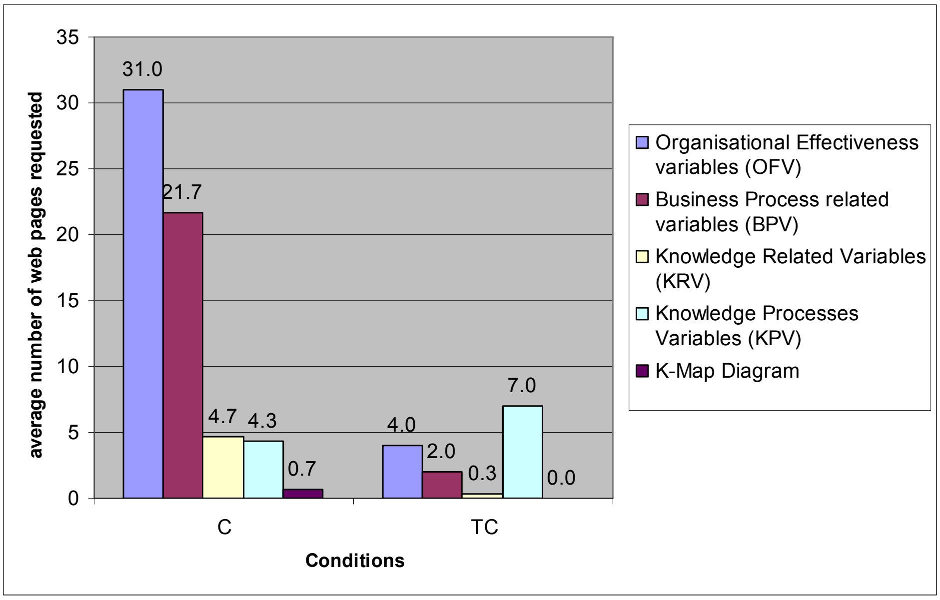


Figure 5-7. The frequency of accessing game indicators in each BM category during the playing sessions.

At first, we thought that the teams in the TC condition hardly accessed the charts and K_map because there was also the numerical table available during the playing process. But, it was found that the average frequency of accessing the numerical table that contains all game variable for the teams in the TC condition is on average 9(s.d.=6.2, N=3) times. Compared with the frequency of accessing the same information of the teams in the T condition was on average 15(s.d.=12.5, N=3). Thus, the average frequency of the teams in the TC condition in accessing the numerical table is also low.

We can not directly generalise and associate this last finding with the prediction saying that the teams in the TC condition did not use the information about the game indicators during playing, because the average number of accessing the numerical table does not mean that the teams in the TC condition did not interpret the numerical information as the numerical table presents a large list of game indicators. It can happen that in one access, a player can obtain more information about more than one game indicator. However, we use this finding as an additional observation to the chatting analysis in the previous section. Technically, it was impossible to obtain objective data about whether a team does obtain and interpret certain indicators in a numerical table and which indicators a team interprets in particular.

In the first hypothesis, we predicted the effectiveness of the communication process to be TC > C > T using four indicators: the level of overall information exchange participation; equal distribution profiles of communication processes in the group decision making phases, the occurrence of sharing the interpretation of numerical information over the decision making phases, and the number of sharing deeper cognitive numerical interpretations. However, the results for the effectiveness of the communication process shows that the teams in the T condition are more effective in their communication process than the teams in the TC and C conditions, although this result is not too convincing because the three experimental conditions did not clearly differ in sharing deeper cognitive numerical information showed by high standard deviations. Comparing the effectiveness of the communication process in the TC and C condition, it was found that the teams in the TC condition actually shared more numerical information and were not too focused in their communication process on decision making in terms of “just selecting the game interventions” than the teams in the C condition. But it is likely that the teams in the TC condition encountered difficulties in playing and understanding the game. The frequency of accessing the chart packages and the numerical table of the teams in the TC condition turned out to be, unexpectedly, very low. In general, we could not confirm our predictions in the first hypothesis concerning differences in effectiveness of the communication process between the three experimental conditions. We concluded that the effectiveness of the communication process in the T condition is the best compared to the other two conditions, and the TC condition is slightly better than the C condition but the teams in the TC condition tend to face difficulties in the playing process.

5.8.4 The intermediate outcomes of the communication process

The intermediate outcomes of the communication process are observed on three indicators: the average number of game quarters played, the average time used in each quarter, and the average use of the game budget. Below the results are described.

For the average number of game quarters played, we noticed that most of the teams almost reached the end of the game (quarter 10). The average number of game quarters played in the teams of the C, T, and TC conditions are respectively 8.3(s.d.=.58, N=3), 8.7(s.d.=.58, N=3), and 9.0(s.d.=.0, N=3), which indicates that all the teams in the TC condition played the game completely. Thus, on average the teams in the TC condition played the most game quarters, and the teams in the T condition played more game quarters than the teams in the C condition.

Regarding the average amount of time spent in a game quarter, the teams in the C, T, and TC condition spent, on average, respectively about 39(s.d.=16), 37(s.d.=13), and 35(s.d.=22) minutes in a game quarter. Although there are no large differences between these averages, we conclude that the relation in terms of more time spent is C > T > TC. We also noticed that the standard deviation in the TC condition is rather high, meaning that the variations of the amount of the time spent by the teams in a quarter are high. We further analysed the average amount of time spent in each experimental condition.

In Figure 5-8, the time spent by the teams in all conditions in quarter 10 is excluded from our analysis because of two reasons: (1) inconsistency of the recording system in the KM Quest server, and (2) not all teams reached the end of the game. Some of the players did not close their web browser program, and leaving the KM Quest website staying open during the after playing session measurement. This caused the logging system in the web server to incorrectly record the time spent in quarter 10.

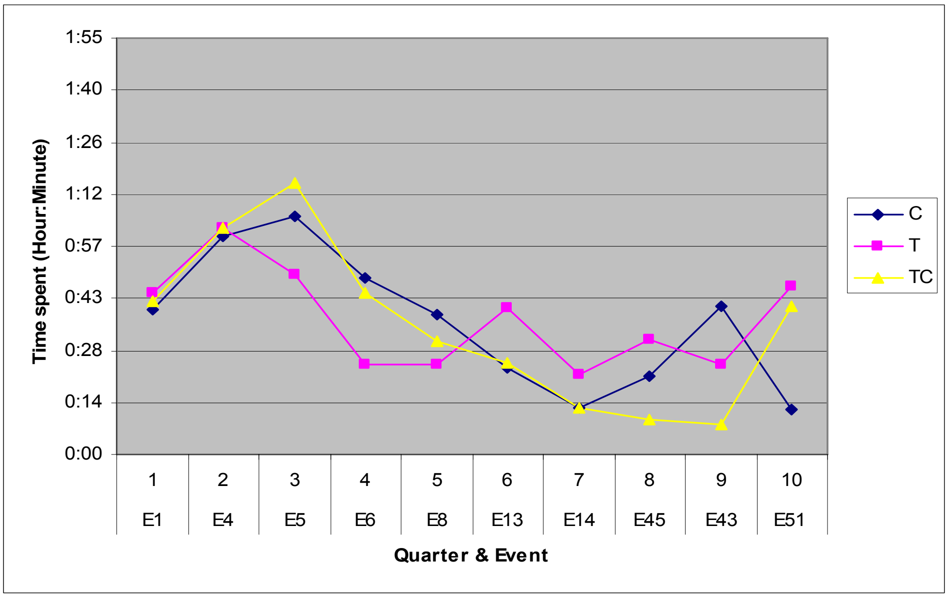


Figure 5-8. The average time spent in each game quarter (hours:minutes).

In Figure 5-8, in terms of average amount of time spent in each quarter, we can see that every experimental condition reached its peak time in quarter 3. The time spent by the C and TC conditions declined steadily for the quarters 4 to 7. For some reasons, this continued in the TC condition until quarter 9. But in the C condition, the time spent increase again for quarters 8 and 9. We believe that the teams in the TC condition were less able to regulate their playing activities compared to the teams in the C condition and tend to gradually lose their interest in playing.

Although the average amount of time spent in each quarter tends to be gradually reduced in the C and TC conditions, the teams in the T condition seem to be able to regulate their playing activity and stay active depending on the type of event. In quarter 6, the average amount of time spent by the teams in the T condition suddenly increases, and the event was a surprise event about an explosion in a plant. This could have led to an increase in the attention and activity for teams in the T condition. Why this did not occur in the other two conditions is hard to explain.

Regarding the use of the game budget, the teams in the C condition spent on average about 1,620,000 Euro (s.d.$_{\text{Ccond}}$= 270,046.2 Euro, N=3) or about 54% (s.d.$_{\text{Ccond}}$= 9.0%, N=3) from the total game budget. The teams in the T condition spent about 1,605,000 Euro (s.d.$_{\text{Tcond}}$= 585,000.0 Euro, N=3) or about 53.5% (s.d.$_{\text{Tcond}}$= 19.5%, N=3) from the total game budget. The teams in the TC condition spent about 1,763,333 Euro (s.d.$_{\text{TCcond}}$= 258,956.2 Euro, N=3) or 58.7% (s.d.$_{\text{TCcond}}$= 8.6%, N=3) from the total game budget. We conclude that in terms of amount spent of the game budget, though the differences are small, TC > C > T.

With the above findings, we could only partly confirm our predictions in the second hypothesis. The teams in the TC condition, on average, played the most game quarters and spent on average the least amount of time in a quarter but used most of the game budget. The teams in the C condition, unexpectedly, played the least game quarters and spent the most amount of time but used an intermediate amount of the game budget. The teams in the T condition played an intermediate number of game quarters and spent an intermediate amount of time in a quarter, but spent least of the game budget. With these findings, although the differences are small, we conclude that for the intermediate outcomes of the communication process the teams in TC condition are the best ones, the teams in the T condition are the intermediate ones, and the teams in the C condition are the worst ones. We accept the second hypothesis partly.

5.8.5 The quantity of the decision outcomes

The third hypothesis is about the quantity of the decision outcomes in terms of the average number of submitted game interventions during playing. During playing, teams in the C, T, and TC conditions submitted on average 24.3(s.d.=4.04, N=3), 24.0(s.d.=8.89, N=3), and 27.7(s.d.=6.66, N=3) game interventions. This is on average 2.9(s.d.=1.5, N=3), 2.8(s.d.=2.05, N=3), and 3.1(s.d.=1.57, N=3) game interventions submitted by each team in every game quarter.

This partly confirms our third hypothesis. We concluded that the teams in the TC condition produced the largest quantity of decision outcomes compared with the other two conditions. However the quantity of decision outcomes produced by the T and C conditions was almost equal.

5.8.6 Group Decision making satisfaction

The data below comes from the Group Decision Making Satisfactory Questionnaire from Brigg and Vreede (1997). As mentioned in the previous chapter, the questionnaire collects information about players' satisfaction on 3 satisfaction dimensions: (i) the process of decision-making, (ii) the outcomes or the results of the decision making session, and (iii) the support or facilitation of the (game) system during the decision-making session. We summarise the results of this questionnaire in Table 5-8.

Table 5-8. Group decision making satisfaction index.

Cond.	GS	N	M(s.d.)
C	PROCESS	9	3.3(.49)
	OUTCOMES	9	3.5(.81)
	SUPPORT	9	3.7(.79)
T	PROCESS	9	3.9(.75)
	OUTCOMES	9	3.6(.83)
	SUPPORT	9	3.9(.85)
TC	PROCESS	9	3.1(.87)
	OUTCOMES	9	3.2(.87)
	SUPPORT	9	3.9(.59)

Note: the index is on a 5-point rating scale (1 = unsatisfactory to 5 = satisfactory). None of the average scores differ significantly at p < .05 in the Kruskal-Wallis Test.

Overall results in Table 5-8 indicate that the players in the three experimental conditions are rather satisfied with the overall group decision making process. Although the results from the teams in the T condition are slightly more positive than the teams in other two conditions, we did not find any significant differences between experimental conditions. All results were tested with the non-parametric Kruskal-Wallis Test. It was found that the results are not significantly different

($\chi^2_{process}$= 4.629, df=2, $p_{process}$ =.099; $\chi^2_{outcomes}$= 1.069, df=2, $p_{outcomes}$ =.586; $\chi^2_{support}$= .506, df=2, $p_{support}$=.777). With this evidence, we rejected the fourth hypothesis. Thus, there is no difference in players' satisfaction with the group decision making between the experimental conditions.

5.8.7 Learning outcomes

To test the fifth hypothesis about the learning outcomes after playing KM Quest, the pre- and post-test scores of KM knowledge test are compared within and between experimental conditions.

Pre- and post-test scores were measured by using the KM knowledge test (Christoph et al., 2003). This test measures two types of knowledge; (i) General knowledge of KM, and (ii) Strategic knowledge of KM. The maximum score is 48 points.

Table 5-9. Mean and standard deviation of KM knowledge test scores.

Cond.	N	PRE M(s.d.)			POST M(s.d.)			Diff. (post – pre)		
		GK	SK	TOTAL	GK	SK	TOTAL	GK	SK	TOTAL
C	9	2.1 (1.4)	14.8 (5.9)	16.9 (5.8)	1.6 (1.3)	15.7 (6.5)	17.3 (6.9)	-.6 (1.8)	.9 (8.8)	.4 (8.3)
T	9	1.2 (1.4)	11.6 (6.4)	12.8 (6.0)	1.4 (1.5)	11.0 (5.7)	12.4 (5.3)	.2 (1.6)	-.6 (10.1)	-.4 (9.6)
TC	9	1.8 (1.2)	15.6 (5.8)	17.3 (6.0)	1.0 (.9)	15.3 (6.3)	16.3 (6.1)	-.8 (1.1)	-.2 (9.1)	-1.1 (9.9)

Notes: GK= general knowledge (max. score=12); SK= strategic knowledge (max. score=36); TOTAL= GK+SK (max. score=48); Diff.= difference between post- and pre-test scores.

Table 5-9 shows that the average total scores on the pre- and post-test in all experimental conditions are very low. The differences between pre- and post-test total scores are not significant based on the Wilcoxon signed ranks test (z_{Ccond}=-.296, p_{Ccond}=.767; z_{Tcond}=-.178, p_{Tcond}=.859; z_{TCcond}=-.178, p_{TCcond}=.859). These findings indicate that generally there is no learning effect in each experimental condition.

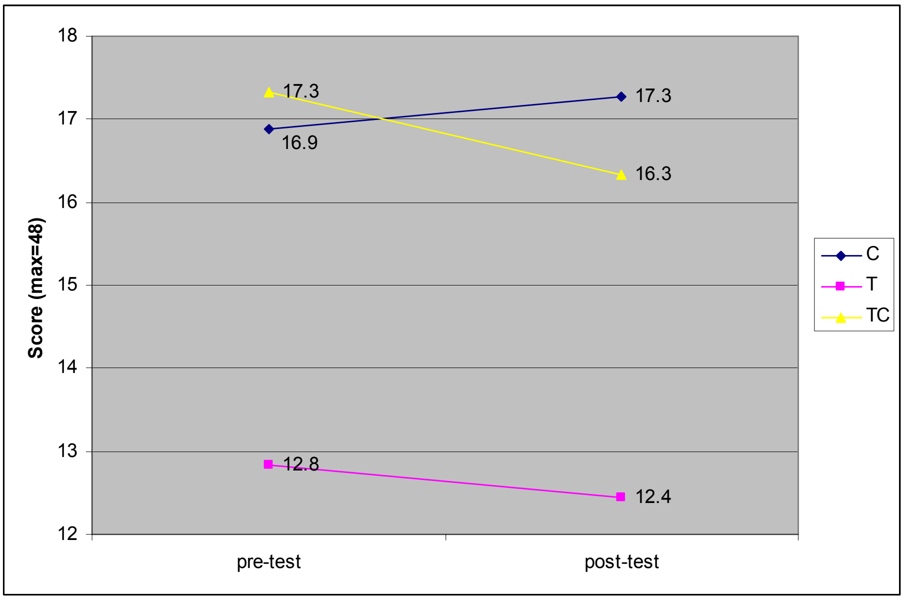


Figure 5-9. Pre- and post-test total scores from KM test.

As shown in Figure 5-9, there are some differences of pre- and post-test scores between experimental conditions. However, the Kruskal-Wallis test did not confirm a significant difference of pre- and post-test total score between experimental conditions (pre-test: $\chi^2_{TOTAL}=2.935$, df=2, p=.231; post-test: $\chi^2_{TOTAL}=2.604$, df=2, p=.272). At this point we conclude that the teams in the three experimental conditions have equally very low prior knowledge about KM before and after the playing sessions. It is rather striking to see that a KM Quest collaborative playing session does not only fail to provide significant learning outcomes but even leads to negative learning outcomes in the T and TC conditions.

A further analysis is done by dividing the total score of the pre- and post-test into 2 sub-sections. This analysis is conducted to investigate the player's achievements on the two types of KM knowledge: general KM knowledge (GK) and strategic KM knowledge (SK). In Figure 5-10 and Figure 5-11, we can see the learning outcomes based on these two test sub-sections.

Figure 5-10 shows that there is a small positive difference between the pre- and posttest scores on generic knowledge (GK) in the T condition. However, the Wilcoxon signed ranks test did not confirm a significant difference ($z_{Tcond}=-.575$, $p_{Tcond}=.565$). The negative difference between pre- and post-test GK score found in the C and TC condition was also not statistically significant ($z_{Ccond}=-.791$, $p_{Ccond}=.429$; $z_{TCcond}=-1.841$, $p_{TCcond}=.0.66$).

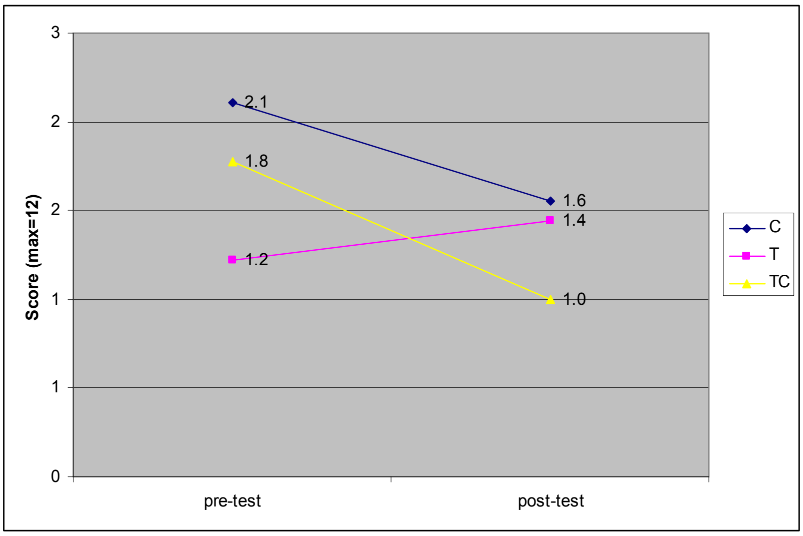


Figure 5-10. Pre and post-test scores on general knowledge section from KM test.

Figure 5-11 shows that there is a small positive difference between pre- and post-test of strategic knowledge (SK) in the C condition. The Wilcoxon signed ranks test (z_{Ccond}=-.534, p_{Ccond}=.594) was not significant. The negative difference between pre- and post-test SK score found in the T and TC condition were also not statistically significant (z_{Tcond}=-.-237, p_{Tcond}=.813; z_{TCcond}=-.059, p_{TCond}=.953).

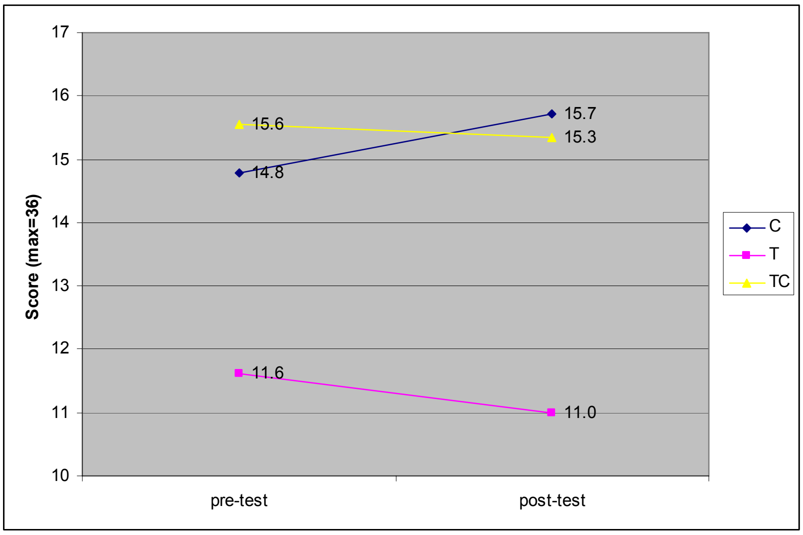


Figure 5-11. Pre- and post-test scores on strategic knowledge section from KM test.

Comparisons of two sub-sections of pre- and post-test scores (GK and SK) between groups were done by using the Kruskal-Wallis test. It was found that there were no statistically significant differences between the experimental conditions in both pre- (χ^2_{GK}=2.146, df=2, p=.342; χ^2_{SK} =1.840, df=2, p=.399) and post-test (χ^2_{GK} =.610, df=2, p=.737; χ^2_{SK} =2.647, df=2, p=.266).

From these findings, we rejected our fifth hypothesis. It is concluded that in this study, there is no learning effect after playing KM Quest. There was even partly a negative learning effect after playing the game, particularly in the TC condition although it is not statistically significant. It could indicate misunderstandings in building both general and strategic knowledge about KM during playing sessions due to a defective collaborative playing process.

5.9 Conclusions

It was predicted that: *First,* the teams, who are supported with a complete set of numerical information visual representations – the charts, the schematic map, and the numerical table, will communicate much more effectively in the group decision making process, produce the best intermediate outcomes of the communication process, have the highest number of decision outcomes, are much more satisfied with the group decision making process, and attain more positive learning outcomes than those who are supported with either the charts and schematic map only or the numerical tables only; *Second*, the teams, who are supported with the spatial numerical information visual representations only - the charts and the schematic map, will communicate more effectively in the group decision making process, produce better intermediate outcomes of the communication process, have a higher number of decision outcomes, are more satisfied with the group decision making process, and attain more positive learning outcomes than those who are supported with the numerical tables only; *Finally*, the teams, who are supported with the symbolical numerical information visual representations only - the numerical table, will communicate least effectively in the group decision making process, produce the worst intermediate outcomes of the communication process, have the lowest number of decision outcomes, are least satisfied with the group decision making process, and attain the least positive learning outcomes than those who are supported with the spatial numerical information and the combination of the spatial numerical information and the symbolical information. The evidence we found in this study is generally not in line with these predictions.

In terms of supporting *the effectiveness of the communication process in group decision making*, the charts and schematic map in this study were found to be the least effective. In the text-based chatting sessions during playing, the teams participated with the least number of message lines but used the longest sentences. The decision making phases in the teams in this condition were found to be unbalanced – mainly focusing on selecting and implementing the game interventions. The communication profile of group decision making phases in the teams who played with the charts and schematic map, reminds us of the overall results of the preliminary study presented in Chapter 4, which was also found to be straightforward to select the game interventions only. In a further analysis of the content of the chatting sessions, the proportion of the occurrence of sharing numerical information in the group decision making phases was also found to be low. In this study, we conclude that the support of the charts and schematic map was not able to effectively elicit information sharing sessions in group decision making, particularly sharing numerical information. An interesting question can be raised in relation to whether the teams “understood” the benefit of the charts in their group decision making to solve the KM problems, or, in other words, whether the players had prior knowledge about how to link the information taken from the charts to learning and developing KM problem-solving skills. Though the TOGS+ showed that overall the players were skilled in graph *comprehension*, this probably does not imply that they are also skilled in *using* the information from the graphs/charts in a particular problem solving setting.

We conclude that despite the complexity and difficulty to comprehend the numerical information presented in the numerical table, the teams that were supported with this visual representation, unpredictably, did communicate rather more effectively in the group decision making process. They participated with the least number of message lines but exchanged the shortest sentences in the text-based chatting sessions during playing. They also were found to better exchange the numerical information in their group decision making process compared to the teams who were supported with the charts and the schematic map only. As the opposite of the teams who were supported with the chart and schematic map only, who seemed to be more focused on selecting and submitting the game interventions, the teams who were supported with the numerical table were somewhat better in deliberately sharing the relevant information taken from the game indicators. It created a rather balanced communication process over decision making phases. This evidence indicates that despite the teams had symbolical visual information only, they were still able to share the numerical information quite effectively compared to the availability of spatial visual representations.

In terms of how the players who were supported with the combination of the chart and schematic map, and numerical table performed, we did find some evidence that they participated with an intermediate number of message lines and exchanged message of an intermediate length. These teams did share the numerical information during decision making phases almost equally when compared with the teams who were supported with the numerical table only. Moreover, compared to the teams who were supported with the numerical table only the teams who were supported with the combination of the chart and schematic map, and numerical table, did share a rather deeper cognitive numerical interpretation as far as interpreting the data patterns and giving subjective qualitative meaning to the data values. However, if we link this evidence to the frequency of accessing the visualisation packages and the numerical table of the teams who were supported with the combination of the chart and schematic map, and numerical table, we suspect that the teams obtained most information from the three main business indicators in the main user interface of the game, somewhat from the numerical table, and very less from the charts and schematic map. Because of this, we hypothesised that the quality of numerical information shared in the teams who were supported with the combination of the chart and schematic map, and numerical table was rather low, due to less diverse information resources in other teams who were supported with the chart and schematic map or the numerical table only.

Additionally, besides effectiveness of the communication process in terms of sharing numerical information sessions, it was found that there was a high proportion of content about “off-tasks” topics in the teams who were supported with the combination of the chart and schematic map, and the numerical table, particularly for the conversation topics of game and technical orientation. This was not found in the other two experimental conditions. We hypothesised that based on these findings the combination of the chart, schematic map, and numerical table in the game environment in this experiment, tends to confuse instead of support the playing process.

Summarising, we conclude that the support of a numerical table for *the effectiveness of the communication process* is more positive than the support of charts and schematic map or even the combination of charts, schematic map, and numerical tables.

In terms of *the intermediate outcomes of the communication process*, the evidence showed that the teams who were supported with the combination of the chart and schematic map, and numerical table were better in allocating their time, played the most game quarters but also used most of the game budget, compared to the other conditions. Yet, surprisingly, despite the complexity of the numerical information and difficulties to comprehend the numerical information, the teams who were supported with the numerical table were intermediate efficient in allocating their time, playing an intermediate number of game quarters, and used least of the game budget. The teams who were supported with the charts and schematic map were least efficient in allocating their time, played the least game quarters, and used an intermediate amount of the game budget. We concluded that the support of the combination of the chart and schematic map, and numerical table is slightly more effective to achieve better intermediate outcomes of the communication process than the support of numerical table or charts and schematic map only. On the other hand, the support of the chart and schematic map only tends to produce less optimal intermediate outcomes of the communication process than the support of the numerical table only.

In terms of *the quantity of the decision outcomes*, the evidence showed that the teams who were supported with the combination of the chart, schematic map, and numerical table submitted the largest number of game interventions compared to the teams who were supported with the numerical table only or the charts-schematic map only. We did not find a difference in terms of the quantity of the decision outcomes for the teams in the other conditions.

It should be understood that the above conclusions are made based on a non-statistical comparison, due to a small size of the sample. As a consequence, the conclusions are interpretative and have a limited value for generalisation.

The players in all experimental conditions judged *the group decision making process* on three aspects; the decision making process, decision outcomes, and support or facilitation, to be satisfactory. We found no significant differences between experimental conditions. This means that the players in each experimental condition were equally satisfied with the group decision making session. We take this finding as an interesting point to discuss in the future, because according to our analysis of the content of the communication process, which showed a high proportion of the “off-tasks” category, hypothetically the communication process of the teams, who were supported with a combination of the chart, schematic map, and numerical table, would lead to a dissatisfaction with group decision making. We are not able to explain this discrepancy at this moment.

For *the learning outcomes*, the evidence clearly shows that the players in none of the three conditions significantly gained knowledge about KM. The players who were supported with the combination of the chart, schematic map, and numerical table even showed a small negative learning effect, although this is statistically not significant. Moreover, this unexpected conclusion has led us to carefully consider the way the overall collaborative interaction took place in the playing process in terms of the effectiveness of the communication process. We can say that, although we found that the support of the numerical table and the combination of the charts, schematic map, and numerical table contributes to effective information sharing, this process apparently does not lead to positive learning outcomes. We predict that there are several factors that may explain this interrelationship. First, we can see that the pre-test scores in all experimental conditions are extremely low compared to the maximum score. Second, looking at the characteristics of the players who are categorised as beginners, we think that the training module of KM Quest and the preparation for the experiment do not support the players sufficiently in acquiring the minimal amount of prior knowledge needed about KM to play the game and learn KM as an ill-defined problem in the KM Quest environment. However, this finding raises classical issues about difficulties in teaching complex problem solving skill to novice learners. We concluded that the design of the playing process or, in other terms the instructional strategy in the system and the architecture of the system needs to be further investigated.

As a general conclusion, we basically did not find significant effects of the differences of visual representations, as was predicted based on the theoretical framework, in almost all experimental measurement used. However, we found some evidence that most of the teams in each experimental condition did not play the game as purposefully as the intention behind KM Quest, to be an environment for collaborative learning and playing to acquire KM knowledge and skills, implies. At this point we conclude that given the communication condition – text-based chatting sessions, the low level of prior knowledge about the KM domain, the symbolic visual representation of numerical information by means of a numerical table tends to stimulate the group decision making in sharing the essential and relevant information taken from the numerical data better than if they used only the spatial numerical visual representation by means of charts and diagrams. However, deliberately exchanging relevant information with low prior knowledge will not lead to better learning outcomes. Moreover, given the communication condition – text-based chatting sessions, and a low level of prior knowledge, the combination of both symbolic and spatial visual representation by means of charts, diagrams, and numerical tables tends to overload the players with information and confuse them when learning a complex domain such as KM. The combination of the numerical table, charts, and schematic map under the condition of a low level of prior knowledge, is also suspected to lead to a de-motivating effect on playing and communicating in the group decision making when learning a fuzzy domain, because the combination of information overload and the low level of prior knowledge can lead to counter-productive playing and learning interactions, such as off-tasks behaviour.

Overall, we suspect that the behaviour of the players in this study was mainly caused by one or a combination of the reasons elaborated below.

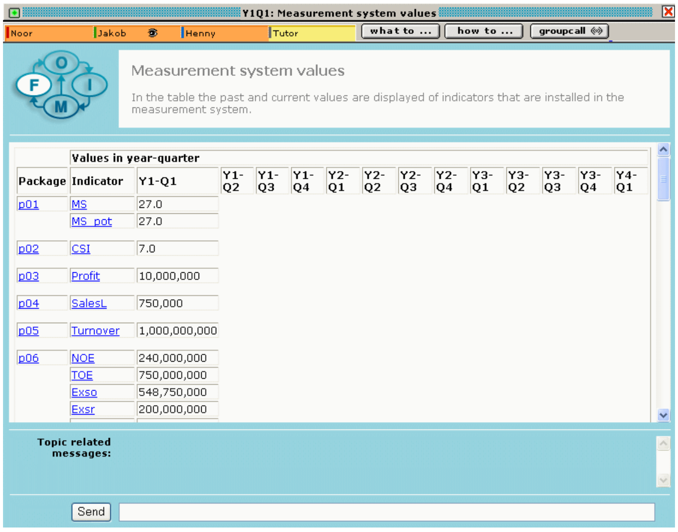
The problem raised by the game and its instructional support characteristics.

As described above, KM Quest tries to encourage a type of learning process to develop problem-solving skills by providing learning opportunities for the acquisition of generic conceptual and strategic knowledge in solving KM problems. This was believed to be achievable by a collaborative discovery learning process. This constructivistic aspect in discovery learning processes characterises the game and its instructional support. The characteristics of the game do not fall exactly into the category of closed (rigid rules) or open simulation games (free-form rules) (see Kriz, 2003; Stahl, 1983). Thus, there are limited gaming and simulation events and less clear directions on how to perform playing and interacting with the system. Consequently, the instructional support does not guide and prompt players directly to look for particular clues and information to solve the problem, beyond the limited advice to players to follow the steps in a given model for the problem-solving strategy (the KM model). In terms of providing feedback, the KM Quest system does warn players if relevant indicators are below a certain threshold, but it does not guide players to make a link between the game indicators and other relevant supportive information to solve the problem. The system enables the players to collaboratively discover more information to support or revise the playing strategies and actions, and then link them to possible consequences of their actions in their own perspective. The effect of the openness of the game environment seems to create a situation where the participants appear “ignorant” of the ways they are generating the playing actions (see Leigh & Spindler, 2004). This situation doubtlessly creates very difficult and complex tasks for novice players because players can interpret the game situation in their own subjective way, leading to problems like playing too fast (see Corbeil, 1999) or possibly “floundering” behaviour (see Veermans, 2003) which appears to be common in problem-based learning where learners have little prior knowledge. The low level of prior knowledge is clearly found for all players in the three experimental conditions. This is possibly the most dominant factor in our study. Though we deliberately selected novice players, this could have been not the right strategy for testing the hypotheses derived from the theoretical framework.

The effect of multiple presentations in the learning environment.

Regarding the low frequency of accessing and average number of sharing numerical information taken from the visual representation of the game indicators, we hypothesised that it reflects a failure to find links and relationships between the domain being learned and representations. Linking multiple representations may not occur due to the following problems: (i) students do not know how to comprehend the visual cues, (ii) students do not know how to relate the visual cues to the domain it is presenting, (iii) and students fail to connect related representations (see Ainsworth, Bibby, & Wood, 1997). The first problem did not apply to our players because according to our measurement, their ability to construct and interpret graphical charts is quite high and there were no differences in player's ability to comprehend them. The second problem was likely happening in our study as comprehending is not the same as using. The third problem seemed to have occurred. Although our visual design strategies intended to provide transparent cues to the players to link several game indicators by grouping the game indicators and providing spatial numerical information in a meaningful way, the frequency of accessing the visualisation packages and the numerical table was found to be low and the average number of sharing deeper cognitive interpretation was also found to be low.

Summarising the two points above, one could imagine that players seem to need sufficient prior knowledge about the domain being learned and also the game environment to benefit from the collaborative learning experience in KM Quest. However, we also predict that the visibility of the graphical information support in the game environment should be better, in order to support the playing process in general or to compensate the low prior knowledge in particular. What we mean with the visibility of the graphical information visual support in the game environment is the way we present the order of the game indicators. Due to necessity of scrolling to find the game indicators in the web pages that present the list of available game indicator in the numerical table (see Figure 5-12) and the visualisation charts (see Figure 5-13), we think that the players lost their attention to the knowledge related and processes indicators, which are very important to be able to play the game and learn the consequence of their actions in the game meaningfully. We are convinced that the combination of these two factors: higher level of prior knowledge and better visibility of the numerical information visual support, will lead to a better playing and learning process.



Measurement system values

In the table the past and current values are displayed of indicators that are installed in the measurement system.

	Values in year-quarter													
Package	Indicator	Y1-Q1	Y1-Q2	Y1-Q3	Y1-Q4	Y2-Q1	Y2-Q2	Y2-Q3	Y2-Q4	Y3-Q1	Y3-Q2	Y3-Q3	Y3-Q4	Y4-Q1
p01	MS	27.0												
	MS_pot	27.0												
p02	CSI	7.0												
p03	Profit	10,000,000												
p04	SalesL	750,000												
p05	Turnover	1,000,000,000												
p06	NOE	240,000,000												
	TOE	750,000,000												
	Exso	548,750,000												
	Exsr	200,000,000												

Figure 5-12 The numerical table used in the T and TC conditions.

Visualisation packages currently available

Below you can find a list of the visualisation packages that are currently available. These packages graphically display data that are based on business and knowledge process indicators.

Visualisation packages can be installed in the Focus phase in the "Establish measurement system worksheet". If you want to know more about the available packages look in the "Visualisation book". If you want to know more about individual indicators look in the "Indicators book".

- p01. Market Share of Coltec
- p02. Customer Satisfaction Index
- p03. Profit
- p04. Level of Sales
- p05. Turnover
- p06. Total Expenses
- p07. Employees
- p08. Average Job Satisfaction of Employees
- p09. Average Time of New Products to Market
- p10. Number of Employees in Marketing
- p11. Level of Sales Based on Marketing
- p12. Average Time to Change for Producing New Products
- p13. Number of Other Employees
- p14. Production Level
- p15. Number of Employees in Research
- p16. Product Quality Index
- p17. Number of Patents
- p18. Number of Products
- p19. Products

Figure 5-13 The list of visualisation packages used in the C and TC conditions.

Obviously the predicted effects of visualisation on the effectiveness of the communication process, the intermediate outcomes of the communication process, the quantity of the decision outcomes, the decision making satisfaction, and the learning outcomes learning outcomes, were rejected in this study. However, it is interesting to investigate that if the above problems in playing sessions will be approached in a different way, for example, providing a better preparation of players and making the visualisation representations more visible to the players, the effects of the visual representation support will occur in those aspects of the playing process, hence lead to better learning outcomes.

In the next chapter, the third empirical study will be presented. The goal of this study is to investigate the effect of an extensive preparation of players before playing on the level of prior knowledge and on the same aspects as addressed in this study. Also a minor modification of the visual representation in the game system was implemented to increase the "visibility" of charts and diagrams which could lead to a higher probability of their use than observed in this study.

6 Study 2[*]: Effects of numerical information visualisation on the effectiveness of group decision making process and learning outcomes: a replication with a different initial situation

6.1 Introduction

Based on the previous study, we suspected that players need a substantial level of prior knowledge - both domain specific and general knowledge - in order to benefit from the playing process in KM Quest and the support of the numerical visual representations. We predicted that by having substantial prior knowledge before the playing session, players will become more knowledgeable in using the numerical information taken from the game indicators in the collaborative communication process during the group decision making process, and consequently they will learn better after going through the decision making processes in the game.

To increase the prior knowledge of the players, we decided to add extra support in the shape of more reading materials, an extensive introduction, and extra preparation sessions before the actual playing. Another aspect mentioned at the end of the previous chapter, was the poor "visibility" of the charts and K_Map in the KM Quest interface. To take this into account, the location of the visual numerical information as presented in the game was slightly modified. These two changes are intended to help players to achieve a substantial level of prior knowledge before entering the playing session and achieve meaningful communication sessions, better intermediate outcomes of the communication process, a larger number of decision outcomes, more satisfaction with the group decision making process, with better learning outcomes as a result.

From this outline it follows that this study can be seen as a replication of the first one, with a different initial situation and a small modification in the visual representations. We are aware of the fact that changing two factors in a replication makes it impossible to measure the effect of each modification separately. However, as we are also interested in increasing the overall effectiveness of learning with KM Quest, separating the effects will be only necessary when learning outcomes are worse than in the previous study. If they are better, both factors should be kept as

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[*] This chapter is written based on:
Purbojo, R., & de Hoog, R. (2004). Learning knowledge management in a collaborative game: Effects of player preparation and visualization of variables. In W. C. Kriz & T. Eberle (Eds.), Bridging the gap: Transforming knowledge into action through gaming and simulation. Munich: Swiss Austrian German Simulation and Gaming Association (SAGSAGA).

Purbojo, R., & de Hoog, R. (2004). The effects of visual information on shaping communication patterns and decision processes in a collaborative and distributed computer based learning environment. Paper presented at the KALEIDOSCOPE SIG First CSCL symposium, 7 to 9 October 2004, EPFL, Lausanne (Switzerland).

probably contributing to better learning outcomes, unless one is concerned about the parsimony of the system.

As a consequence of being a replication, the hypotheses tested in this study are the same as in the previous one; though there are some small changes in the measurements (see section 6.2.4).

The next section gives a brief overview of the experimental procedures and also the modification made in the KM Quest learning environment. After presenting the design and the results of the experiment, conclusions and suggestions for further research are stated.

6.2 Design of the Study

6.2.1 Conditions

In principle this study must essentially be comparable with the previous one. It was decided to follow again the pre- and post-test experimental design with three independent groups as in the previous chapter:

1. Playing with the support of the charts and the schematic map (The C condition).
2. Playing with the support of the numerical table (The T condition).
3. Playing with the support of a table, the charts and the schematic map (The TC condition).

Thus there is no major difference between this study and previous one regarding the experimental conditions.

6.2.2 Participants

For this study we recruited new players from a rather similar population as in the previous study. In the same way as in the previous study, the recruitment of participants only considered novice learners in KM and KM Quest. The population is a mixture of International graduate students and Dutch regular undergraduate students. Twenty-seven students of graduate and undergraduate programs in the Faculty of Behavioural Sciences, University of Twente, registered voluntarily. They received a financial reward of 20 Euro, after finishing the experimental session. The participants were matched into 9 teams based their educational specialisation studies to obtain an equal distribution of the team's ability for each team. Later, each team was randomly assigned to one of the experimental conditions.

6.2.3 Instruments

6.2.3.1 Laboratory settings and its computer facilities

This study was done in the same computer room as in the previous study (see previous chapter for the detailed information). We also used the same room settings, allocation of players, and computer facility.

6.2.3.2 The Learning Environment: KM Quest version 2.0b

The KM Quest version used was almost the same as in the previous study, except that the visualisation in the game environment was slightly modified: First, the main game interface in this version displayed the game indicators for the competence levels in the three knowledge domains of Coltec (marketing, production, and research), instead of market share, profit, and customer satisfaction on the whiteboard. The type of visual representations of the competence level in the interface was also adjusted correspondingly to the experimental condition. Thus, in the T condition the players were supported with only numbers on the whiteboard, in the C condition the players were supported with only visual symbols – icons, and in the TC condition the players were supported with combination of numbers and icons (see Figure 6-1 as an example of the visual representation of the TC condition).

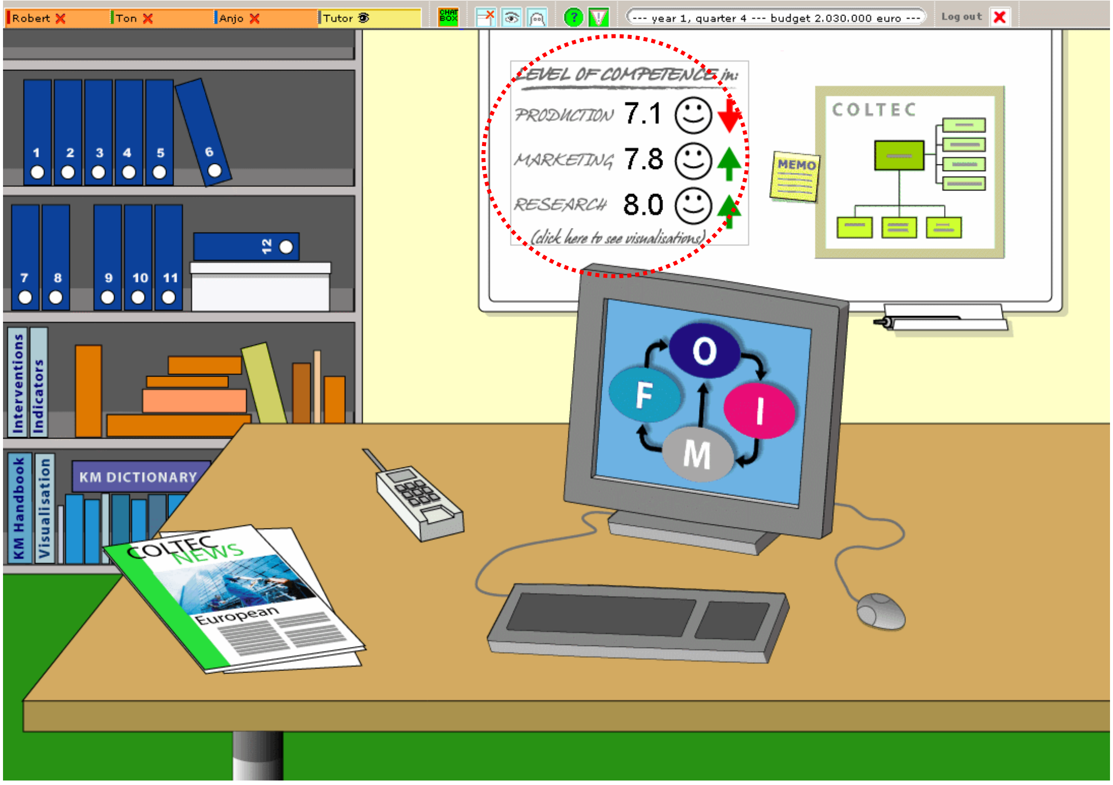
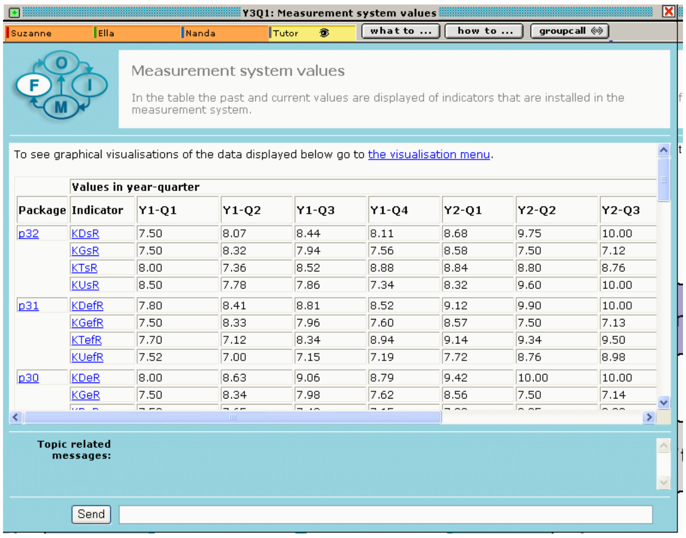


Figure 6-1. The new interface for TC condition.

Second, the original list of the game indicators that was used in the previous study for the T and TC conditions (see Figure 5-12) is turned upside down. The new list of indicators used in this study, as showed in Figure 6-2, presents the indicators in the following order of categories: the knowledge processes, the knowledge related, the business process, and the organisational effectiveness indicators. This modification provided better visibility of important indicators during the playing process without the need to scroll to the end of the web page.

Consequently, the list of available visualisation packages for the C and TC conditions was also modified with the above strategy. In the new list of available visualisation support, we present the K_Map, then visualisation packages in the category of knowledge processes, the knowledge related, the business process, and the organisational effectiveness indicators (see Figure 6-3).



Measurement system values

In the table the past and current values are displayed of indicators that are installed in the measurement system.

To see graphical visualisations of the data displayed below go to the visualisation menu.

	Values in year-quarter							
Package	Indicator	Y1-Q1	Y1-Q2	Y1-Q3	Y1-Q4	Y2-Q1	Y2-Q2	Y2-Q3
p32	KDsR	7.50	8.07	8.44	8.11	8.68	9.75	10.00
	KGsR	7.50	8.32	7.94	7.56	8.58	7.50	7.12
	KTsR	8.00	7.36	8.52	8.88	8.84	8.80	8.76
	KUsR	8.50	7.78	7.86	7.34	8.32	9.60	10.00
p31	KDefR	7.80	8.41	8.81	8.52	9.12	9.90	10.00
	KGefR	7.50	8.33	7.96	7.60	8.57	7.50	7.13
	KTefR	7.70	7.12	8.34	8.94	9.14	9.34	9.50
	KUefR	7.52	7.00	7.15	7.19	7.72	8.76	8.98
p30	KDeR	8.00	8.63	9.06	8.79	9.42	10.00	10.00
	KGeR	7.50	8.34	7.98	7.62	8.56	7.50	7.14

Figure 6-2. The numerical table used in T and TC conditions for this experiment.

Visualisation packages currently available

Below you can find a list of the visualisation packages that are currently available. These packages graphically display data that are based on business and knowledge process indicators.

Visualisation packages can be installed in the Focus phase in the "Establish measurement system worksheet". If you want to know more about the available packages look in the "Visualisation book". If you want to know more about individual indicators look in the "Indicators book".

- p33. Knowledge Map
- p32. Speed of Knowledge Processes in Research
- p31. Efficiency of Knowledge Process in Research
- p30. Effectiveness of Knowledge Processes in Research
- p29. Speed of Knowledge Processes in Production
- p28. Efficiency of Knowledge Processes in Production
- p27. Effectiveness of Knowledge Processes in Production
- p26. Speed of Knowledge Processes in Marketing
- p25. Efficiency of Knowledge Processes in Marketing
- p24. Effectiveness of Knowledge Processes in Marketing
- p23. Average Level of Competence in Marketing
- p22. Average Level of Competence in Research
- p21. Average Level of Competence in Production
- p20. Level of Sales Based on Product Quality
- p19. Products
- p18. Number of Products
- p17. Number of Patents
- p16. Product Quality Index
- p15. Number of Employees in Research

Figure 6-3. The list of the visualisation packages used in the C and TC conditions.

Except the above adjustments, in principle the game environment used in this study was identical with the previous one. As can be seen, the modification took place not in the way the visualisation was designed, but only in the way of where to present the information about available game indicators in the game environment.

The game system also used exactly the same case description and the initial values of the game indicators, and triggered the same order of the game events as in the previous study (see section 5.5.3.2.)

6.2.4 Measurement and observation instruments

The measurement and observation strategy used in this experiment followed the one in the previous study. Three consecutive measurement moments were carried out: before, during, and after the playing session.

6.2.4.1 Before playing

Player's background information

The players' general background information was obtained in exactly the same way as in the previous chapter. The same web form and a pre-test session of TOGS+ were administered.

Measuring KM prior knowledge

It was decided to replace the KM test with the newest version which has different type of questions in the first sub-section and less questions from the case-based essay test in the second section. However this new test measured the same types of knowledge as the previous version: KM general knowledge and KM strategic knowledge that is related with the KM problem-solving model. The first section consists of 20 multiple-choice questions. The second section used the same case description as in the previous study but only consists of 2 essay questions. This new version of the KM knowledge test was administered in the pre-test session to measure KM prior knowledge. This test takes a maximum of 60 minutes to complete.

6.2.4.2 During playing

Log files

We did not change our strategy and observation tools in this part of the experiment. The data recording was done by the server in order to gather data about player's behaviour and communication processes.

6.2.4.3 After playing

Player's satisfaction with the group decision making process

The same questionnaire as in the previous studies, that measures player's satisfaction with the overall group decision making process during the playing session, was used.

Measuring the learning outcomes

A parallel post-test of the new KM test was administered after the playing session. The results from the pre- and post-test sessions will be compared to assess the learning outcomes.

6.3 Procedures

In principle the procedures were nearly the same as in the previous study, but as explained above, the overall learning scenario was extended with extra reading materials and intensive learning preparations prior to the playing session.

Two weeks before playing, the online training module of KM Quest and the introductory reading material to KM and its various models and methods were launched on the internet. Each player was asked study the paper and follow the training module at their own pace. We invited players to attend a classroom session.

One week before the experiment, the classroom session was given (90 minutes). In this session, a lecture from a KM expert was given to provide the players with extra theoretical support and question – answer opportunities. This session also had an interactive lecture on how to solve a game event according to the KM model and its procedures. An example of a KM Quest event was presented and guided by the KM expert, the players were encouraged to solve the event together. In this session, we also emphasised the importance of the numerical information taken from the game indicators and other information available in the system during the problem solving process. The second part of the classroom session was a game system walkthrough, which was given by the experimenter. The players were shown the real environment of KM Quest. This session was meant to encourage players to complete the training module and read the theoretical material carefully prior to the data collection session.

At the day of the data collection, the playing session took place in the computer laboratory. The participants were asked to follow the sitting allocation corresponding to the mapping of their identification number in the computer laboratory room. When all players had found their sitting location, the before playing test sessions (TOGS+ and KM test) were held with a duration of 30 and 60 minutes. The playing session began immediately after finishing the pre-test sessions.

At the beginning of the playing session, a short introductory presentation about the game rules, the main tasks, and other data collection procedures were explained once more by the experimenter. We also refreshed the players' memories about some issues of KM theory and used the first game event as a trial and guided event to instruct and warm-up players to enter the real game. In this trial session, the players were guided to solve the problem together with the experimenter. The players were also asked to become familiar with the chatting process and other important playing activities such as finding supportive information, selecting the game interventions, and submitting the game interventions.

We gave the same instruction as in the previous study: each participant must keep their original identity secret during playing, and they were also asked to carefully and deliberately solve the game events collaboratively and maintain the synchronous chatting sessions without regarding the time limit. They were not asked to solve all game events but must deliberately discuss the problem presented by the game events and find the solutions within the available game budget, 3,000,000 Euro for each team, in a cost-effective way. After the trial session, players were left to play on their own from the second to the tenth quarter.

We used the modified version of KM Quest game environment as described in section 6.2.3.2.

The data collection sessions took about 7 hours totally, including pre- and post-test session, a 45 minutes lunch break and two coffee breaks. The data collection was finished with the post-test session.

6.4 Hypotheses

In this study we will test the same hypotheses as in the previous one.

- The *first hypothesis* concerns the effectiveness of the communication process. It is expected that the effectiveness of the communication process is TC > C > T. The effectiveness of the communication process will be measured by:
    - The level of information exchange participation in terms of *the average number of message lines exchanged* and *the average length of the messages* in each condition (TC > C > T);
    - The profile of the communication processes over the group decision making phases, in terms of *the proportion of the communication processes occurring in the intelligence, design, choice, phases and feedback loop* (see Figure 2-3) will be more equally distributed in TC > C > T ;
    - The occurrence of sharing the interpretation of numerical information in the group decision making phases, in terms of *a high proportion of sharing numerical information of the game indicators in the intelligence phase, design phase, choice phase, and feedback loop* in group decision making process, will be higher in TC > C > T;
    - The number of sharing deeper cognitive numerical interpretations, indicated by *the frequency of the numerical pattern detections or trend analysis*, *the frequency of the interpretation of patterns of the numerical information into subjective evaluations*, and *the frequency of integrating and associating the numerical information with other types of information,* will be TC > C > T.
- The *second hypothesis* concerns the quality of intermediate outcomes of the communication process, which will be better in TC > C >T. This will be indicated with:
    - The *number of game quarters played* (TC > C > T);
    - The *time used in each game quarter* (TC < C < T);
    - The *use of the game budget* (TC < C < T).
- The *third hypothesis* concerns the quantity of the decision outcomes which will be indicated by *a higher number of game interventions submitted* in TC > C > T;
- The *fourth hypothesis* predicts that the player's satisfaction with the group decision making, measured with the Group Decision Making satisfactory questionnaire, will be TC > C > T;
- The *fifth hypothesis* states that the learning outcomes, as measured by the *KM tests*, will be TC > C > T.

6.5 Results

6.5.1 Data processing

All players' answers to the pre- and post-test of the essay test sub-section in the KM knowledge test were scored by the experimenter according to the scoring criteria supplied by the original test constructor. In order to check the consistency of the coding process, we selected 22% of the answers on the essay test as a sample and gave it to a second coder. There was a strong correlation between first and second coder (Pearson correlation, r(96)=.92). This proves the reliability of the judging process and we accepted the first coder's scoring.

The coding process of the chatting sessions followed the same procedure as in the previous study. The chatting sessions were first segmented according to the game quarters. The game quarter segments are the fixed episodes of the communication processes in the group decision making process, because in each game quarter the problem that the players have to solve is different and new. The communication processes during decision making are recurring until reaching the end of the game. With this segmentation we have a maximum of 9 communication observation opportunities per team (The maximum number of observation opportunities is 9 quarters multiplied by 9 teams is equal to 81 episodes). In each episode of communication observation we applied the conversational content segmentation and applied the code scheme to categorise each segment. The analysis of the chatting session was done using the same procedure and coding scheme as in the previous study (see section 5.8.1).

Fifteen percent, or a minimum of 50 segments (Neuendorf & Skalski, 2002; Reiss, 1985) from the total segments was used as the coding sample to be given to an independent second coder. Cohen's Kappa inter-rater agreement coefficients for the three experimental conditions, C, T, and TC, are respectively .74, .71, and .71, meaning that there is an acceptable agreement between the first and the second coder. As a consequence the coding of the first coder are the data used in the analysis.

6.5.2 Background information of the players

6.5.2.1 Demographic information of the players

The demographic information of the player presented in this section was taken from the identification form that collects information about age, gender, educational background, and familiarity with internet chatting tools. This information is needed to see if there were variations that could influence the comparison between the experimental conditions.

Table 6-1. General summary of background of the players.

Cond.	N(n)	Mean Age (year; month)	s.d. Age (year; month)	Gender	Education
C	3(3)	29; 7	7; 4	6 ♀	8 BSc.
T	3(3)	28; 10	6; 10	8 ♀	9 BSc.
TC	3(3)	26; 4	6; 10	6 ♀	7 BSc.

Note: ♀= female participants; BSc. = holding Bachelor of Science degree

Although Table 6-1shows an almost equal background for the players, there are some small variances of gender and educational background for the players in each experimental condition. In this study again, the advertisement of KM Quest attracted more female participants. The percentage of the female students in the target population is about 69%. As also said in the previous study, we do not have an explanation for this phenomenon and but it might be a point of interest for the sociology of gaming in general. As there is also no reason to assume that females are either better or worse than males in learning KM through game playing, we do not have to worry about this skewed distribution in the sample, as long as the difference between the conditions is not too large. As the consequence of having a larger target population, the educational background of the players is also more varied. We noticed that the players in the T condition have a slightly higher educational background than the players in the other conditions. We assumed that this difference in educational background will also not influence players' ability and capability to learn KM and play the game.

Concerning familiarity with chatting tools, almost all players stated that they are very familiar with these. They usually use the chatting tool almost on a daily basis. Only one participant from the TC condition reported that she does not use chatting regularly. The average time that participants in the C, T, TC conditions on average spent on chatting is respectively 5.6, 6.8, 5.9 hours/week. There are some differences between the conditions, but as the number of hours spend is considerable in each condition, we do not expect this to influence the results.

Compared to the previous study, the players in this study had a slightly lower educational background (see section 5.8.2.1). This implies that when we find better results in this experiment, these are not likely to be due to an increase in this factor.

6.5.2.2 Graphing construction and interpretation skills

The TOGS+ test was administered to detect differences between player's general ability to construct and interpret graphical charts.

Table 6-2. Average and standard deviation scores of TOGS+

Cond.	N	M (s.d.)
C	9	20.7(7.6)
T	9	21.1(6.2)
TC	9	23.6(6.6)
Total	27	21.8(6.7)

Note: The maximum score for this test is 32.

Table 6-2 shows that the average scores for the conditions are relatively equal. Non-parametric statistical analysis with the Kruskal-Wallis test confirmed that there is no statistically significant difference between the conditions (χ^2 = .909, df =2, p=.635). This result fits our expectation that the experimental conditions have an equal ability to construct and interpret graphical charts, although we learned from the previous study that a high score of TOGS+ does not guarantee that players are able to use the data from the charts and the schematic map to build understanding. Theoretically, we assume from this that the players in this study are also equally capable to extract visual information from charts and diagrams or even reproduce visual understanding using data from charts, diagrams, and a numerical table. Cronbach's alpha reliability coefficient for TOGS+ in this study is .89.

Compared to the previous study, the overall result of TOGS+ this study (M=21.8, s.d.= 6.7) is slightly lower than the previous one (see section 5.8.2.2). It means that the players in this study have a slightly lower ability in graphing skills. This implies that when we find better results in this experiment, these are not likely to be due to an increase in this factor as well.

6.5.3 Effectiveness of the communication process

Similar to the previous chapter, the effectiveness of the communication process is compared based on five indicators: the level of information exchange participation, the profile of the communication processes over the group decision making phases, the occurrence of sharing the interpretation of numerical information, and the number of sharing cognitive numerical interpretations. The next sub-sections address each of them. Similarly with the previous chapter, the unit of analysis in this section is also mostly the team. The analysis was done on the basis of the communication process in each team in the experimental conditions. The analysis done in this section is purely explorative. Due to the small number of observations in each condition, we are unable to test findings statistically. This creates a limitation that the testing of hypothesis is judged on the basis of the average values and the standard deviations. The drawback of this method is that the conclusions drawn in this section have a limited value for generalisations.

6.5.3.1 The level of information exchange participation

During the entire playing process, the teams in the T condition on average exchanged the most chat lines (M=707.7, s.d.=145.11 lines, N=3) and used the shortest sentences per line (M=5.5, s.d.=1.10 words). This may indicate that the teams used simpler sentences in their chatting session compared with the other two conditions. The teams in the C condition exchanged an intermediate number of chat lines (M=588.3, s.d.=278.15 lines, N=3) but used the longest sentences (M=6.9, s.d.=1.85 words, N=3). It is noticeable that the standard deviation in the C condition is high. This means that the variance of the number of the chat lines between the teams in this condition is also rather large. This may indicate that in terms of the average number of message lines, these teams had a lower level of information exchange participation but used longer sentences to convey meaning in the chatting session. The teams in the TC condition show the lowest level of information exchange participation with the least number of lines (M=568.3, s.d.=176.42 lines, N=3) but an intermediate sentence length (M=6.1, s.d.=.99 words).

From this we can conclude that our prediction in the first part of the first hypothesis is not confirmed. The teams in the T condition participated in the information exchange process at the highest level by exchanging on average the largest number of message lines per quarter, but used the shortest chat message line length. The teams in the TC condition exchanged on average the least message lines, but with an intermediate line length. The teams in the C condition exchanged on average an intermediate number of message lines but with the longest chat message line length.

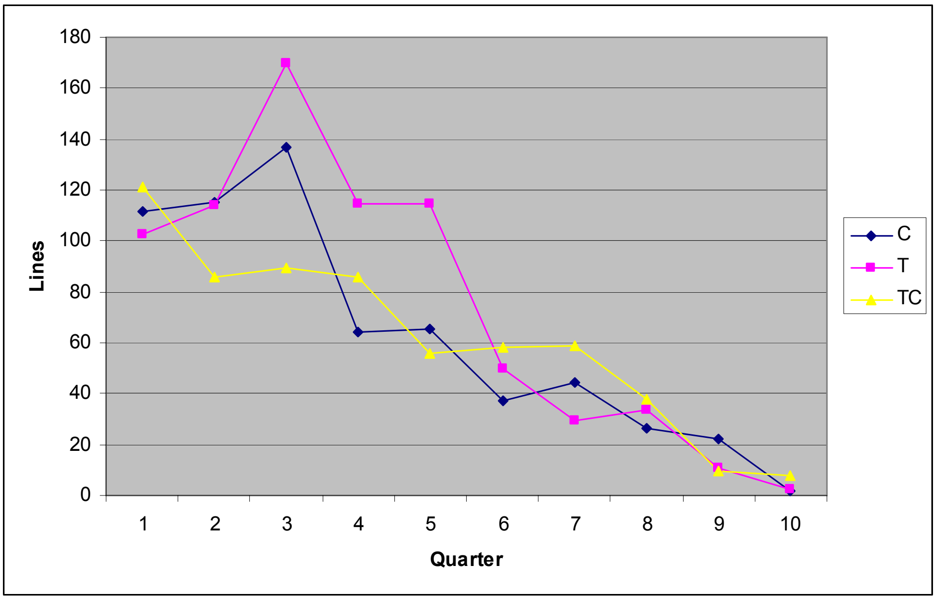


Figure 6-4. The chatting sessions based on the average number of chat lines.

Figure 6-4 shows that in this experiment all teams started with a high average number of message lines, with a high level in the early game quarters compared with the previous study. Generally, in the first four game quarters, the level of overall information exchange participation is relatively high. The teams in the C and T condition reached the peak number of message lines at quarter 3. This peak is not found in the teams in the TC condition whose average steadily declined over the quarters. We can not find an explanation for this phenomenon. From Figure 6-4 it can also be seen that overall, the level of participation of the teams in all experimental conditions dropped over the game quarters. Ups and downs, as observed in the previous study, are lacking. This can be a consequence of the fact that over time, players tend to become familiar with KM Quest, leading to more tacit understanding about what to do.

Compared with the findings in the previous study, these averages are rather high. This means that the level of information exchange participation in this study is clearly higher than in the previous study. Also it seems that the teams in the T and TC conditions in this experiment were not as event-focused as found in the previous study. We can observe that the number of chatting message lines in quarter 6 (internal threat type of event) of this study peaked less than was found in the previous one.

6.5.3.2 The profile of communication processes over the group decision making phases

In order to obtain the profile of the communication processes based on the group decision making phases, we used the data from the coded chat log files.

The profile of the communication processes shows their distribution over the group decision making phases in the overall playing process. Just as in the previous chapter, this profile is made based on the proportion of the total communication processes in the decision making phases of each experimental condition. Although there was a maximum of 9 game quarters in the playing session, in later observations we noticed that not all teams reached all of them (see section 6.5.4. for the detailed data).

From the overall communication process, the average number of segments containing the chatting contents in the C, T, and TC conditions that could be classified on, is respectively 109.0(s.d.=59.5, N=3), 92.3(s.d.=34.8, N=3), and 126.3(s.d.=26.6, N=3). Compared with the previous study, the average number of segments in this study is about twice as high. This may indicate that the communication processes in this study are more intense than in the previous study. Based on these segments a proportional distribution profile of communication processes is drawn in Figure 6-5. This profile reflects the proportion of the communication processes occurring in the decision making phases.

Since we expect that the result of this study is comparable to the previous one, we use the same proportion distribution criteria as in the first study. The analysis of the profile of the communication process over the decision making process is done with these criteria (see p.134).

In Figure 6-5, we can see that the profile of the communication processes over the group decision making phases in all three conditions are not close to our criteria.

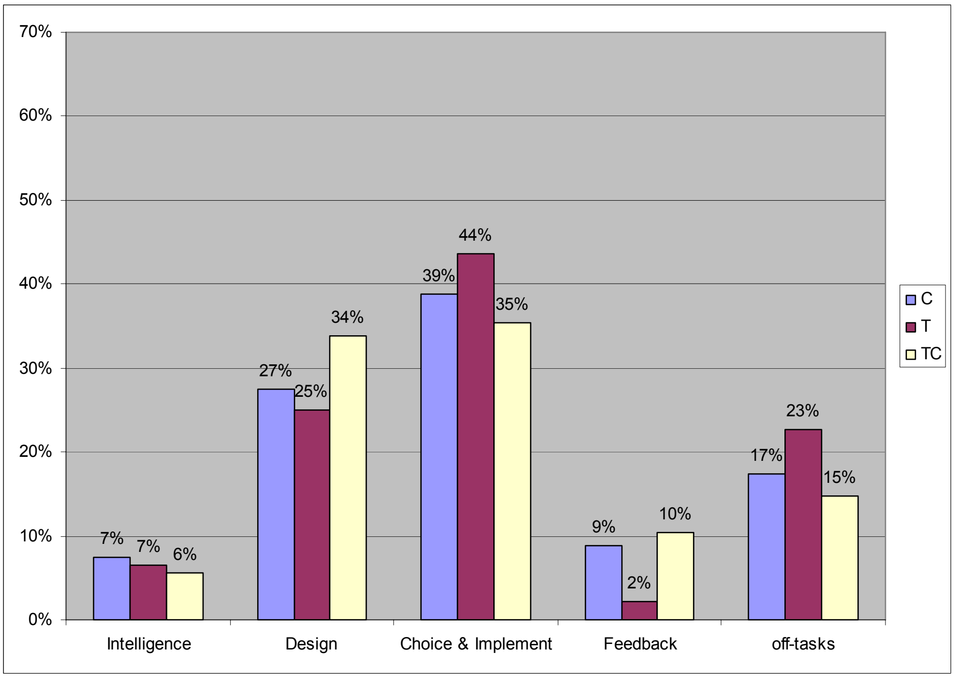


Figure 6-5. Proportional distribution of communication processes over the decision making phases.

In a further analysis, we can see in Table 6-3 that the difference between observed percentage values and expected percentage values of the profile of communication of the teams in the C condition is slightly less than the other two conditions. This means that the profile of the communication process over the group decision making phases in the C condition is slightly more balanced compared to the other two conditions according to our criteria. We can see that the difference between the scores in the C and TC condition is very small; we would say that quantitatively the difference of the profile between these two conditions is very similar ($\sum D_{\text{Ccond}}$=57% and $\sum D_{\text{TCcond}}$=58%). Additionally, the profile of communication of the teams in the TC condition is more balanced compared to the T condition.

Table 6-3. Differences between observed and expected values in the communication profiles.

	Intelligence			**Design**			**Choice & Implement**			**Feedback**			**off-tasks**			**∑D**
	O	E	D	O	E	D	O	E	D	O	E	D	O	E	D	
C	7	22.5	15.5	27	22.5	4.5	39	22.5	16.5	9	22.5	13.5	17	10	7	**57**
T	7	22.5	15.5	25	22.5	2.5	44	22.5	21.5	2	22.5	20.5	23	10	13	**73**
TC	6	22.5	16.5	34	22.5	11.5	35	22.5	12.5	10	22.5	12.5	15	10	5	**58**

Notes: O= observed value (%); E= Expected value (%); D= the difference between observed and expected values; **∑D** *= total of differences (%).*

The communication processes in the teams in the T condition were for 44% in the "choice and implementation" and 25% in the "design" phase, and less in the "feedback" loop, only 2% from all their segments. Also "off tasks" messages are rather frequent in the teams in the T condition, about 23% from all their segments.

This could be an indication that the players in the T condition focused less of their communication process on making decisions and providing feedback from their past decisions.

The profiles for the teams in the C and TC conditions are rather similar. The teams in the C condition have a slightly higher proportion in the “choice and implementation” phase (39% from their segments) than the teams in the TC condition (35% from all their segments). But on the other side the teams in the TC condition have a higher proportion (35% from their segment) in the “design” phase than the teams in the C condition (27% from their segments). This indicates that the communication profile of the teams in the C condition is slightly more focused on reaching decision outcomes and trying to implement them than the teams in the C condition.

Moreover, the profile of the teams in the TC condition is rather unique, the proportion of the communication processes in the categories “Design” and “Choice and Implement” phase are almost equally high, 34% and 35%. This could be an indication that the teams in the TC condition focused almost equally on elaborating their ideas or finding more information and making a selection of the game interventions or trying to implementing the game interventions. We also find that the proportion in the “off-task” category in this condition is lower, 15%, compared with the other two conditions.

In Figure 6-5 and Table 6-3, we can see that there is a slightly higher proportion of the communication processes in the “feedback loop” in the decision making phases of the teams in the C and TC conditions, respectively 9% and 10% compared with the T condition. Although the percentages are relatively small, we think they may be an indication of the support of charts and the schematic map in the information exchange sessions in the decision making phases. The feedback loop communication process might consist of evaluating past decisions with sharing a cognitive numerical information interpretation. Looking at the percentages of the codes in this category, we believe that providing feedback, which is taken from the cognitive interpretation of the spatial numerical information of the charts and schematic map, seems to be done more easily than with the symbolic numerical information of the numerical table.

From above findings, we could not fully confirm our prediction in the second part of the first hypothesis. It is concluded that on average the profile shown by the teams in the C condition seems to be slightly more balanced than that of the teams in the TC condition. However, we found that the profile of the teams in the T condition shows the teams to be rather focused on selecting and implementing the decisions, and they are also communicating more about tasks that are not directly related to the decision making phases.

Compared to the previous study, we can see that the profile of communication processes over the decision making phase, in the teams of the T condition deviates almost equally from our criteria (71% in the first study and 73% in the second study, see Table 5-5 and Table 6-3). The same evidence is found when comparing the deviation of the profile of the teams in the TC condition (56% in the first study and 58% in the second study). However, the difference of the deviation in the profile of the teams in the C condition is much lower in this study (77% in the first study and 57% in the second study). We conclude that quantitatively the profile of the teams in the C condition is much more balanced in the second study.

However, qualitatively the profile of the proportional distribution of the communication processes over the decision making phases in the teams of the T condition in the second study is different in terms of having less in the design phase, much less in the feedback loop, and much more in the off-tasks category, compared to the first study. The profile of the teams in the TC condition in the second study is more in the design phase and in the choice & implement phase, and less in the off-tasks category compared to the first study. The profile of the teams in the C condition is the second study is less in the intelligence phase, much more in the design phase, and less in choice and implement phase, more feedback, but more off-task category, compared to the first study.

At this point we conclude that the profile of the teams in the C condition in this study is not only more balanced compared to the teams in the other conditions, but also compared to the first study. Markedly, the profile of the teams in the T condition in the second study is much less balanced compared to the first study. We conclude also that the profile of the teams in the TC condition in the second study is somewhat more balanced than in the first study.

6.5.3.3 The occurrence of sharing the interpretation of numerical information

The detailed analysis of the content of the chatting session is focused on finding the episodes where teams share the information taken from the game indicators. The result of this analysis is presented in Table 6-4.

Table 6-4. The average proportion of the occurrence of the interpretation of numerical information in decision making phases.

			C(N=3)		T(N=3)		TC (N=3)	
Simon's problem-solving phases	**Comm. Sub-tasks in decision making phases**	**Comm.task in KM Quest (CODE)**	M(s.d.)%		M(s.d.)%		M(s.d.)%	
INTELLIGENCE	• recognise problems	Ev	5.1	(3.5)	5.0	(2.8)	4.1	(1.5)
	• diagnose characteristic	IndEv	**$2.4^{(1)}$**	(0.1)	$1.6^{(2)}$	(1.5)	$1.5^{(3)}$	(0.5)
DESIGN	• obtain information	Ind	$9.5^{(3)}$	(6.2)	$5.9^{(2)}$	(7.8)	**$10.4^{(1)}$**	(1.8)
		InInd	$7.0^{(2)}$	(4.3)	$1.6^{(3)}$	(2.8)	**$7.6^{(1)}$**	(4.3)
		GC	1.3	(1.7)	0.0	(0.0)	0.9	(1.0)
		NC	0.0	(0.0)	0.6	(0.5)	0.2	(0.4)
	• develop ideas	Foc	4.6	(1.9)	6.4	(4.4)	5.1	(2.6)
		Obj	5.2	(2.5)	10.5	(2.9)	9.6	(4.3)
CHOICE	• evaluate alternative	Bud	4.3	(4.3)	5.2	(3.3)	2.3	(1.2)
		IntBud	5.6	(1.4)	3.4	(3.7)	3.1	(1.0)
	• selection	Int	17.3	(1.8)	20.0	(10.6)	11.1	(0.7)
		IndInt	$6.3^{(3)}$	(4.1)	$7.2^{(2)}$	(5.0)	**$12.8^{(1)}$**	(4.7)
		EvInt	5.0	(3.7)	6.1	(5.6)	2.9	(1.2)
		IndIntEv	$0.3^{(3)}$	(0.5)	**$1.7^{(1)}$**	(2.9)	$1.4^{(2)}$	(0.6)
IMPLEMENT	• implementation	Plan	0.0	(0.0)	0.0	(0.0)	1.8	(1.9)
Feedback		Eva	3.1	(1.2)	0.6	(0.5)	4.9	(1.8)
		EvFedB	0.9	(0.9)	0.6	(0.5)	0.0	(0.0)
		IndFedB	$4.8^{(2)}$	(0.2)	$1.0^{(3)}$	(1.7)	**$5.5^{(1)}$**	(2.0)
Off task		Soc	0.9	(0.9)	0.7	(1.1)	0.9	(1.0)
		GO	10.4	(3.2)	15.8	(10.3)	9.1	(6.4)
		TO	6.0	(4.9)	6.1	(2.8)	4.3	(1.5)
		Cls	0.0	(0.0)	0.0	(0.0)	0.3	(0.6)
		Ref	0.0	(0.0)	0.0	(0.0)	0.2	(0.4)
		TOTAL	100%≈109.7		100%≈92.3		100%≈126.3	

Notes: the values in this table present the percentage of the occurrence of the codes in each decision making phase; the greyed out categories are the ones that are relevant for measuring shared use of the numerical information from the game indicators; ***(1)*** *= first rank; (2)= second rank; (3)= third rank.*

In Table 6-4 we can see that in the early phase of group decision making - the "intelligence" phase, the process of communication to share the cognitive interpretation of numerical information taken from the game indicator is related with diagnosing characteristics of the problem (*IndEv* category). The results do show a slightly higher proportion in the C condition (M_{Ccond}=2.4%, s.d.$_{Ccond}$=.1%) than the other two conditions (M_{Tcond}=1.6%, s.d.$_{Tcond}$=1.5%; $M_{TCcond=}$1.5%, s.d.$_{TCcond}$=.5%).

In the "design" phase, we observed that the teams in the C condition on average showed a more frequent interpretation of single game indicators, (*Ind* category, M_{Ccond}=9.5%, s.d.$_{Ccond}$=6.2%), than the teams in the T condition (M_{Tcond} =5.9%, s.d.$_{Tcond}$ =7.8%) and a slightly less frequent one if compared with the teams in the TC condition (M_{TCcond} =10.4%, s.d. $_{TCcond}$ =1.8%). Moreover, the teams in the TC condition showed the highest proportion (M_{TCcond} =7.6%, s.d. $_{TCcond}$=4.3%) in the category that indicates sharing combined information from multiple game indicators, the *InInd* category, than the other two conditions. Particularly, the teams in the T condition showed a very low proportion (M_{Tcond}=1.6%, s.d.$_{Tcond}$ =2.8%) in this category. From this, we have the impression that in the communication process of the "design" phase, the teams in the C and TC conditions tend to share the numerical information more frequently than the teams in the T condition.

In the "choice and implement" phase, where players have to elaborate their decision alternatives, sharing interpretation of game indicators is expected to occur as well. However, we found that the proportion of the communication processes that are meant to exchange numerical information taken from the game indicators, the *IndInt* category, in the teams in all experimental condition is not very high (M_{Ccond}=6.3%, s.d.$_{Ccond}$=4.1%; M_{Tcond}=7.2%, s.d.$_{Tcond}$=5.0%; M_{TCcond}=12.8%, s.d.$_{TCcond}$=4.7%). In the category of communication processes that are meant to exchange information that links the information taken from the game indicator and the information taken from the game event, the *IndIntEv* category, we found also a low proportion (M_{Ccond}=.3%, s.d.$_{Ccond}$=.5%; M_{Tcond}=1.7%, s.d.$_{Tcond}$=2.9%; M_{TCcond}=1.4%, s.d.$_{TCcond}$=.6%).

In the "feedback loop", two dominant categories appear to make a difference between the teams in the T, C and TC conditions. We can see from Table 6-4 that the teams in the T condition have a very low proportion of evaluation (*Eva* category: M_{Tcond}=*.6% and s.d.* $_{Tcond}$=*.5%,* and indicator feedback (*InFedB* category) in the entire playing session (M_{Tcond}=*1.0%,* *s.d*$_{Tcond}$=*1.7%*). In contrast, the teams in the TC condition showed the largest proportion of these two labels (*Eva*, M_{TCcond}=*4.9%* *s.d.*$_{TCcond}$=*1.8%; IndFedB,* M_{TCcond}=*5.5%, s.d.* $_{TCcond}$=*2.0%*) compared with the teams in the C condition (*Eva*, M_{Ccond}=*3.1% s.d.* $_{Ccond}$=*1.2%; IndFedB,* M_{Ccond}=*4.8%, s.d.* $_{Ccond}$ =*.2%*).

Considering this, we could not fully confirm our prediction in the third part of the first hypothesis. We conclude that the proportion of sharing the interpretation of numerical information in the group decision making phases for the teams in the TC condition is higher than for those in the other two conditions. Compared to the teams in the C condition, the proportion of sharing the interpretation of numerical information the teams in the T condition is higher.

Compared to the previous study (see Table 5-6), we notice two major differences. First, one must remember that the overall proportion is calculated based on the average number of segments containing the chatting contents in the three experimental groups. As mentioned earlier, the average number of segments in this study is about twice the number found in the previous study. Second, the occurrence of the proportion of sharing the interpretation of numerical information in the group decision making phases for all teams in this study is also higher. A difference in the proportion of the codes between the first and the second study is only found in *InInd* category (compare Table 5-6 and Table 6-4). When observing Table 5-6 we notice that the proportions that are related with conversations about game events in the previous study is rather lower than in this study (see *Ev*, *IndEv*, *EvInt*, and *EvFedB* categories). Thus, we concluded that quantitatively the occurrence of the sharing the interpretation of numerical information in this study is not only two times higher than the previous one, but the scope of the sharing the interpretation of numerical information in this study is also broader.

6.5.3.4 The number of sharing deeper cognitive numerical interpretations

For the fourth, and final, part of the first hypothesis, we need to find an indication of the frequency of sharing "deeper" cognitive interpretations of the numerical information presented in the game indicators in the decision making phases. In the fourth part of the first hypothesis we said that the frequency of the numerical pattern detections or trend analysis, the frequency of the interpretation of patterns of the numerical information into subjective evaluations, and the frequency of integrating and associating the numerical information with other types of information than in the numerical information will be TC > C > T.

Table 6-5. Average number of sharing cognitive numerical interpretations.

Labels	C M(s.d., N=3)	T M(s.d., N=3)	TC M(s.d., N=3)
IndFedB(1)	0.0 (0.0)	0.0 (0.0)	0.3 (0.6)
IndFedB(2)	**3.0 (2.0)**	0.7 (1.2)	**3.3 (2.5)**
IndFedB(3)	**3.0 (2.0)**	1.0 (1.7)	**3.0 (1.7)**
IndFedB(4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
IndEv(4)	1.3 (1.2)	0.7 (0.6)	0.3 (0.6)
Ind(1)	0.3 (0.6)	0.3 (0.6)	1.3 (0.6)
Ind(2)	**7.3 (5.5)**	**3.0 (3.6)**	**4.7 (3.8)**
Ind(3)	**4.7 (4.2)**	**4.3 (7.5)**	**4.7 (0.6)**
Ind(4)	0.7 (0.6)	1.3 (1.2)	**2.7 (1.5)**
InInd(1)	0.3 (0.6)	0.0 (0.0)	0.3 (0.6)
InInd(2)	**5.0 (4.0)**	1.0 (1.7)	**4.3 (3.2)**
InInd(3)	**4.7 (5.0)**	0.3 (0.6)	**5.3 (3.8)**
InInd(4)	**1.7 (2.1)**	0.7 (1.2)	**2.3 (3.2)**
GC(1)	0.3 (0.6)	n.a n.a	0.0 (0.0)
GC(2)	1.0 (1.0)	n.a n.a	1.0 (1.7)
GC(3)	0.7 (1.2)	n.a n.a	0.0 (0.0)
GC(4)	0.0 (0.0)	n.a n.a	0.0 (0.0)
NC(1)	n.a n.a	0.0 (0.0)	0.0 (0.0)
NC(2)	n.a n.a	0.0 (0.0)	0.0 (0.0)
NC(3)	n.a n.a	0.0 (0.0)	0.0 (0.0)
NC(4)	n.a n.a	0.0 (0.0)	0.0 (0.0)
IndInt(1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
IndInt(2)	**2.7 (3.1)**	1.3 (1.5)	**3.7 (4.7)**
IndInt(3)	0.3 (0.6)	0.7 (0.6)	**2.0 (2.6)**
IndInt(4)	0.0 (0.0)	0.0 (0.0)	0.3 (0.6)
IndIntEv(4)	0.0 (0.0)	0.3 (0.6)	0.7 (1.2)
TOTAL	**37.0 (2.1)**	**15.7 (1.1)**	**40.3 (1.8)**

Notes: the values are the average number of sharing cognitive numerical interpretation during the playing process. "n.a." = not available.

When observing the column of the T condition in Table 6-5, it is easy to see that the teams in this condition on average have the lowest frequency of sharing their cognitive interpretation derived from the game indicators (TOTAL: $M_{Tcond}=15.7$, s.d.$_{Tcond}=1.1$) compared with the other two conditions (TOTAL: $M_{Ccond}=37.0$, s.d.$_{Ccond}=2.1$; $M_{TCcond}=40.3$, s.d.$_{TCcond}=1.8$). Particularly, the teams in the T condition rarely shared information taken from a cognitive interpretation that relates multiple game indicators and game indicators to other indicators or other information (see *InInd(1), InInd(2), InInd(3),* and *InInd(4)* category of column T).

In terms of detecting patterns in or trend analysis of the numerical information (*Ind(2)* category), we can see that the teams in the C condition did share this the most frequent ($M_{Ccond}=7.3$, s.d.$_{Ccond}=5.5$) compared with the other two conditions ($M_{Tcond}= 3.0$, s.d.$_{Tcond}= 3.6$; $M_{TCcond}= 4.7$, s.d.$_{TCcond}=3.8$). However, in contrast with this, the finding concerning the differences in the average frequency of the information sharing sessions that are meant to exchange rather "deep" cognitive interpretation *Ind(3)* values, indicating a subjective interpretation of the pattern or trend in the numerical information (such as "market share is going bad") showed almost no differences between the three experimental conditions ($M_{Ccond}= 4.7$, s.d.$_{Ccond}= 4.2$; $M_{Tcond}= 4.3$, s.d.$_{Tcond}= 7.5$; $M_{TCcond}= 4.7$, s.d.$_{TCcond}=.6$). We found on average that the frequency of the *Ind(4)* category, which indicates relating information derived from a game indicator to other game indicators or instances, such as finding relationships between two or more variables or a game event, is slightly higher in the TC condition ($M_{TCcond}=2.7$, s.d.$_{TCcond}=1.5$) than in the other two conditions ($M_{Ccond}= .7$, s.d.$_{Ccond}=.6$; $M_{Tcond}=1.3$, s.d.$_{Tcond}=1.2$).

Observing the frequency of sharing cognitive interpretations from multiple game indicators, we could hardly find this in the T condition. This type of information sharing can be found almost equally frequent in the TC and C conditions. However, similar to the findings in the category of interpreting a single indicator, the teams in the C condition seems to be slightly more frequent in sharing *InInd(2)* ($M_{Ccond}=5.0$, s.d.$_{Ccond}=4.0$) than the teams in the TC condition ($M_{TCcond}=4.3$, s.d.$_{TCcond}=3.2$). Opposed to the previous finding, the teams in the TC condition seems to be slightly more frequent ($M_{TCcond}=5.3$, s.d.$_{TCcond}=3.8$) in sharing *InInd(3)* than the teams in the C condition ($M_{Ccond}=4.7$, s.d.$_{Ccond}=5.0$).

In the category of relating the interpretation of the game indicators with the selection of the game interventions, we found that the teams in the TC condition shared slightly more frequently deeper cognitive interpretations than the teams in the C condition. We can see that the average frequency of *IndInt(2), IndInt(3),* and *IndInt(4)* in the TC condition are respectively 3.7, (s.d.$_{IndInt(2)}=4.7$), 2.0 (s.d.$_{IndInt(3)}=$ 2.6), and .3 (s.d.$_{IndInt(4)}=.6$), while in the C condition the average frequency of the first two labels is respectively 2.7, (s.d.$_{IndInt(2)}=3.2$), .3 (s.d.$_{MIndInt(3)}= .6$). It was found that both the teams in the C and T condition did not share the deepest cognitive interpretation of the numerical information while elaborating the decision alternatives (*IndInt(4)* category).

By looking at the overall findings of the number of sharing deeper cognitive numerical interpretations, we confirm our predictions in the fourth part of the first hypothesis. We conclude that compared to the teams in the C and TC conditions, the teams in the T condition did this not only the least frequent, but also shared very little information that consist of complex interpretations of the numerical information, such as interpretation of multiple game indicators and integrating and associating the numerical information with other types of information than the numerical information. The teams in the TC condition shared more frequently cognitive interpretations of numerical information from the game indicators and have also a more frequent sharing of deeper cognitive interpretation of the numerical information than the teams in the C condition. However, the differences of sharing deeper cognitive interpretations of numerical information between the teams in the C and TC conditions are rather small. We conclude that visual representations in the C condition is better for stimulating a more frequent interpretation of patterns of numerical information or pattern analysis of single and multiple game indicators, whereas visual representations in the TC condition is better to stimulate a more frequent interpretation of patterns of the numerical information into a subjective evaluation.

Compared to the previous study, the teams in the T condition in this study shared their deeper cognitive numerical interpretation about twice less frequent. We find this to be unexpectedly low. At this point, it is difficult to find a reason that can explain this, except assuming that it has a close relation with the high proportion of “off-task” communication in the decision making phases. It may reflect difficulties in playing and/or communicating in the game. The teams in the C and TC conditions in this study obviously more frequently share cognitive numerical interpretation than the teams in the C and TC condition in the previous one. We conclude that the support of the visual representation in the C and TC conditions in this study is much better than in the previous one.

6.5.3.5 Additional observations on the way the teams accessed the numerical information

The visualisation packages in the system were requested on average about 95.3 (s.d.= 66.9, N=3) and 80.0 (s.d.=24.3, N=3) times by the teams in the C and TC conditions. This means that the teams in the TC condition accessed in the visualisation packages more frequently than the teams in the C conditions. The detailed frequency of accessed game indicators in each BM category is presented in Figure 6-6.

Comparing the frequencies shown in Figure 6-6, there are remarkable differences in accessing the K_Map and the visualisation packages that depict the knowledge process variables (KPV) between these two experimental conditions. The teams in the TC condition did access the K_Map much more often than the teams in the C condition. But the teams in the C condition accessed the visual packages in KPV much more often than the teams in the TC condition.

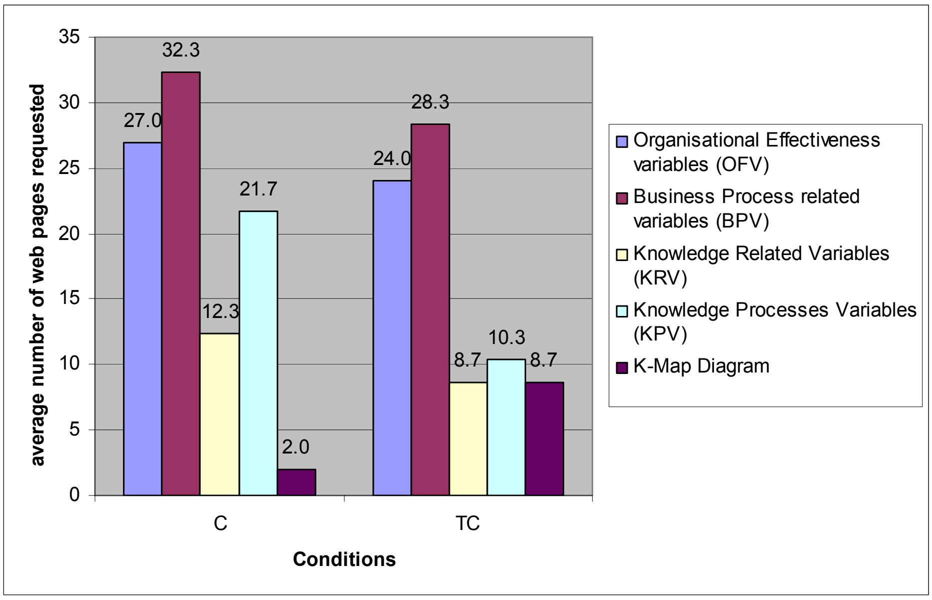


Figure 6-6. The frequency of accessed game indicators in each BM category.

The average number of accessing game indicators in the C and TC conditions in this study is obviously higher when compared with the previous study, particularly for the TC condition. Compared to Figure 5-7, we can also see that in Figure 6-6 the frequency of accessing the business process related variables (BPV) is higher than accessing the organisational effectiveness variable (OFV). Interestingly, this observation may explain why the teams in the TC condition exhibit a more frequent in sharing of cognitive interpretations of numerical information than the teams in the C condition.

In the overall playing session, the teams in the T and TC condition accessed the numerical table on average 14.7 (s.d.=7.4, N=3) and 12.3 (s.d.=6.7, N=3) times respectively. We did not find a big difference between these two values in this study. Though the teams in the TC condition have an option to access the numerical table, the tendency is that they rather prefer to access the numerical information from the visualisation packages than the numerical table.

In the first hypothesis, we predicted the effectiveness of the communication process to be TC > C > T using four measurements: the level of overall information exchange participation; equal distribution profiles of communication processes over the group decision making phases, the occurrence of sharing the interpretation of numerical information, and the number of sharing deeper cognitive numerical interpretations. Below, we elaborate each of them.

We concluded that the numerical table elicits the highest participation level with the shortest sentences compared to charts and schematic maps or the combination of charts, schematic maps, and numerical table. The combination of charts, schematic maps, and numerical table leads to the lowest participation level but with an intermediate sentence length. The chart and the schematic map lead to an intermediate participation level but with the longest sentences. We think that regarding the participation level, the numerical table seems to provide a situation where players tend to become engaged in a higher level of information exchange participation than the other two types of visual representation.

Regarding the distribution profiles of communication processes over the group decision making phases, the evidence showed that the teams who were supported with the charts and the schematic map tend to have a more balanced profile than those who were supported with the combination of charts and a schematic maps or the numerical table only. The teams who were supported with the numerical table only tend to focus on selecting and trying to implement the game interventions. However we found that the difference between the balanced profiles of the teams in the C and TC conditions is quantitatively very small.

Regarding the occurrence of the numerical information exchange sharing sessions in the decision making phases, the visual representations that combine the charts, the schematic map, and the numerical table appear to support the teams to effectively exchange the numerical information taken from the game indicators in "the design" phase of the group decision making process and create a meaningful "feedback loop" that verifies teams' past decisions. The support of the numerical table on the sharing of numerical information episodes in the group decision making phases is found to be less effective than the support of the visual representation that combines the charts, the schematic map, and the numerical table. However it is better than the support of visual representation by means of the charts and the schematic map only. However, we found that the difference between the support of the charts and the schematic map only, and the numerical table only, is very small.

Regarding the number of sharing deeper cognitive numerical interpretation, we conclude that the effect of the combination of charts, schematic map, and numerical tables on the number of sharing deeper cognitive numerical information interpretation, is slightly more marked than in the charts and schematic map only. We also could confirm, to some extent, that the teams who are supported only with the charts and the schematic map do show a higher frequency of sharing episodes that indicate cognitive numerical interpretation by detecting numerical patterns or trends. On the other side, the teams who are supported with the combination of the charts, the schematic maps, and the numerical table, do show a slightly higher number of sharing cognitive interpretations that consist of interpreting information of trend analysis with their personal evaluation and relating interpretation of game indicators with other information resources in the game. The most important findings in terms of the number of sharing numerical information in the teams who are supported only with the numerical table is the low frequency of sharing the numerical information in the feedback loop, which means that the teams do not consider sharing numerical information in this phase to be important to verify their past decisions. It seems to us that the density of the numerical information presented in the numerical tables is not beneficial to stimulate the feedback loop of the decision making phases.

Considering the evidence above, even though with some variations in the findings, we accept our first hypothesis. We concluded that to, some extent, the support of the combination of charts, schematic maps, and numerical table for an effective communication process is better than the support of the charts and schematic maps only. However the differences are very small. The support of the numerical table is found to be not effective for the effectiveness of the communication process.

The results for the effectiveness of the communication processes of the decision making processes in this experiment are obviously far better than in the previous study. In this study we found some evidence that the combination of charts, the schematic map, and the numerical table tends to support teams to achieve more effective communication processes than in other visual representations. Contrary to the previous study, we found that the communication process in the teams who were supported with the numerical table only is least effective.

6.5.4 The intermediate outcomes of the communication process

When evaluating the intermediate outcomes of the communication process from the teams in the three experimental conditions, the number of game quarters played, the time spent in each game quarter, and the budget used, were gathered and analysed.

The average number of game quarters played by the teams in the C, T, and TC conditions are respectively 8.0(s.d.=1.0, N=3), 8.3(s.d.=1.15, N=3), 8.3(s.d.=.58, N=3). These findings clearly indicate that not all teams in each condition played all quarters (9 events in 10 game quarters). Compared to the previous study, the average number of game quarters played in each experimental condition in this study is slightly lower, but not much.

Within the average number of game quarters played, on average, the teams in the C, T, and TC conditions spent respectively about 33 minutes (s.d.= 31 minutes), 39 minutes (s.d.=35 minutes), and 35 minutes (s.d.=28,) in each game quarter. It is noticeable that the variance of the average time spent per quarter in each experimental condition is rather large. This is also visible in the line graph in Figure 6-7. We can observe that on average all the teams in the experimental conditions reached their peak time at quarter 3. After this quarter, the trend in each experimental condition declines gradually, except for the teams in the TC condition in quarters 5, 6 and 7 where a levelling effect occurs. The teams in the T condition suddenly spent a bit more time in quarter 8 compared with the 2 quarters before. We did not find clear evidence that can explain this.

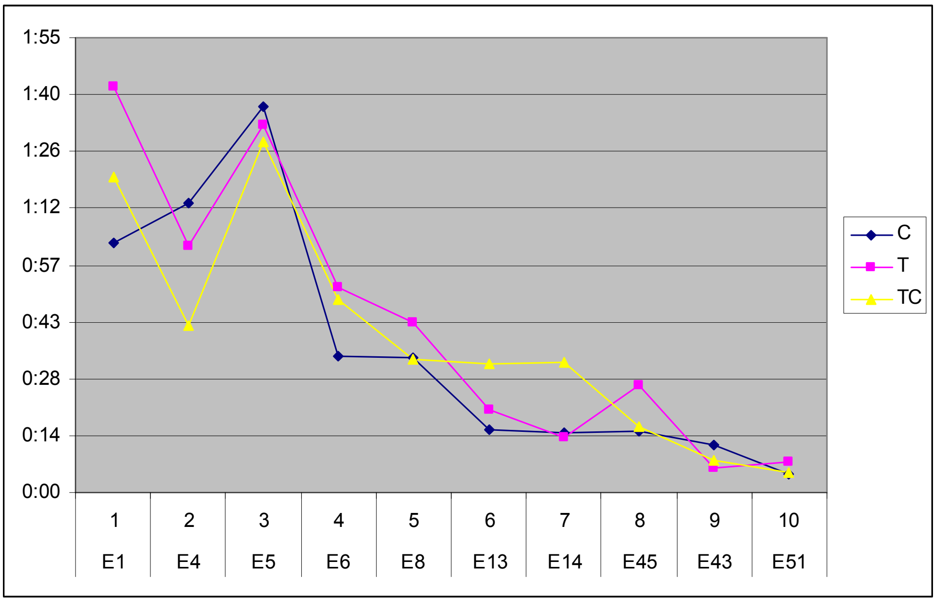


Figure 6-7. The average time spent in each game quarter.

We only noticed that the fluctuation of the time in each experimental condition in this experiment is not as varied as found in the previous study (see Figure 6-7).

The average use of the game budget of the teams in the C condition is 1,928,333 Euro (s.d.= 77,835.3 Euro, N=3) or 64.3% (s.d.= 2.59%, N=3) from the total game budget. The teams in the T condition spent on average 2,165,000 Euro (s.d.= 103,319.9 Euro, N=3) or 72.2% (s.d.= 3.44%, N=3) from the total game budget. The teams in TC condition spent 2,336,667 Euro (s.d.= 72,168.8 Euro, N=3) or 77.9% (s.d.=2.41%, N=3) from the total game budget. These numbers are obviously larger than the ones found in the previous study.

With these findings we could not confirm all the predictions described in our second hypothesis. We concluded that the teams in the C condition produced better outcomes than the teams in the TC and T conditions. Although the teams in the C condition played slightly less game quarters compared to the teams in the TC and T conditions, they used the least average time per quarter and the least game budget. On the other hand we concluded that in general the teams in the TC and T conditions produced the intermediate communication outcomes almost equally. The teams in the TC and T conditions on average played about the same number of game quarters and but the teams in the T condition used the longest time per quarter and used the largest amount of the game budget, on the other hand the teams in the TC condition used an intermediate amount of time, but used the largest amount of the game budget. It seems to us that the teams in the T condition produce a slightly better quality of intermediate outcomes of the communication process than the teams in the TC condition.

6.5.5 The quantity of the decision outcomes

On average the teams in the C, T, TC conditions submitted 28.7 (s.d.=3.06, N=3), 32.7 (s.d.=3.06, N=3), and 32.3(s.d.=1.15, N=3) game interventions. With these results we calculated that in each quarter the teams in the C, T, and TC conditions submitted on average 3.2(s.d.=.34, N=3), 3.6(s.d.=.34, N=3), and 3.6(s.d.=.13, N=3) game interventions. Compared with the previous study, these results indicate that the players in each condition are relatively more productive in submitting the game interventions in this study.

With this finding, we could not confirm our third hypothesis. In terms of submitting game interventions in both the overall game and per quarter, it was found that the teams in the T and TC condition submitted both a higher number of game interventions compared with the teams in the C condition, but did not differ in this respect between them.

6.5.6 Group decision making satisfaction

Table 6-6 shows that players in all conditions are generally satisfied on the three dimensions of the group decision making satisfaction index. In particular, the process of making decisions and the facilitation or the support during making decisions, were judged equally positive in all experimental conditions. The Kruskal-Wallis test confirmed that there is no difference on the index dimensions of the decision process and the facilitation/support of the system between the three experimental conditions ($\chi^2_{process}$=.156, df=2, $p_{process}$=.925; $\chi^2_{support}$=1.127, df=2, $p_{support}$=.569).

However, players in the C and TC condition judged the outcomes of decision-making process more positive than players in the T condition. The Kruskal-Wallis test confirmed the differences for the decision outcomes between the three experimental conditions ($\chi^2_{outcomes}$= 7.089, df=2, $p_{outcomes}$=.029). This means that the players in the T condition judged the decision outcomes to be rather negative (M_{Tcond}=3.4 s.d.$_{Tcond}$=.75, N=9) compared with the teams in the other two conditions (M_{Ccond}=4.1 s.d.$_{Ccond}$=.53, N=9; M_{TCcond}=4.3, s.d.$_{Ccond}$=.56, N=9).

Table 6-6. Group decision making index.

Cond.	GS	N	M(s.d.)
C	PROCESS	9	3.8(.89)
	OUTCOMES	9	4.1(.53)*
	SUPPORT	9	3.7(.63)
T	PROCESS	9	3.8(.71)
	OUTCOMES	9	3.4(.75)*
	SUPPORT	9	3.8(.78)
TC	PROCESS	9	4.0(.88)
	OUTCOMES	9	4.3(.56)*
	SUPPORT	9	3.6(.85)

*Notes: the index is on a 5-point rating scale (1= unsatisfactory to 5= satisfactory). Mean scores of the Outcomes judgment do differ at *p < .05 in the Kruskal-Wallis Test.*

With these findings we accept the fourth hypothesis partly, with the remark that the satisfaction index score between the three experimental conditions did only differ in the dimension of satisfaction with the decision outcomes. It was found that the satisfaction with the decision outcomes in the TC condition is more positive than in the C and T condition, and the C condition is more positive than the T condition.

Compared to the previous study, the overall average index scores from the group decision making questionnaire in this study is slightly higher, particularly the average index score for the players in the TC condition (see Table 5-8 and Table 6-6).

6.5.7 Learning outcomes

The pre- and post-test of the KM knowledge test were administered in two sections: the multiple-choice general knowledge test and the essay case-based strategic knowledge test. Results are shown in Table 6-7.

Table 6-7. Mean and standard deviation of the KM knowledge test scores.

Cond.	N	PRE M(s.d.)			POST M(s.d.)			Diff. (post-pre)		
		MC	CB	TOTAL	MC	CB	TOTAL	MC	CB	TOTAL
C	9	10.0 (1.6)	4.1* (2.7)	14.1* (2.9)	10.2 (2.6)	9.8* (3.1)	20.1* (4.6)	.2 (2.5)	5.8 (2.6)	6.0 (3.8)
T	9	8.8 (2.2)	4.6 (3.3)	13.4* (2.8)	10.7 (1.5)	6.8 (2.6)	17.5* (3.4)	1.9 (2.8)	2.2 (4.3)	4.1 (4.0)
TC	9	10.6 (1.6)	6.5* (5.1)	17.1* (5.7)	11.3 (3.0)	11.1* (3.2)	22.4* (5.3)	.8 (2.9)	4.6 (5.6)	5.4 (5.1)

*Notes: MC = Multiple-Choice test section (Max = 20); CB = Case-based test section (Max = 24); TOTAL = total score (Max = 44); *p < .05 Wilcoxon signed rank test found a significant difference between pre- and post-test measurement.*

Although Table 6-7 shows that there are relatively small differences between pre- and post-test scores between the experimental conditions, the Wilcoxon signed ranks test that was used to test differences between pre- and post-test scores for each experimental condition, confirmed that there are significant differences for the total scores (z_{Ccond}=-2.549; p_{Ccond} = .011; z_{Tcond} = -2.077; p_{Tcond} =.038; z_{TCcond} = -2,312; p_{TCcond} = .021).

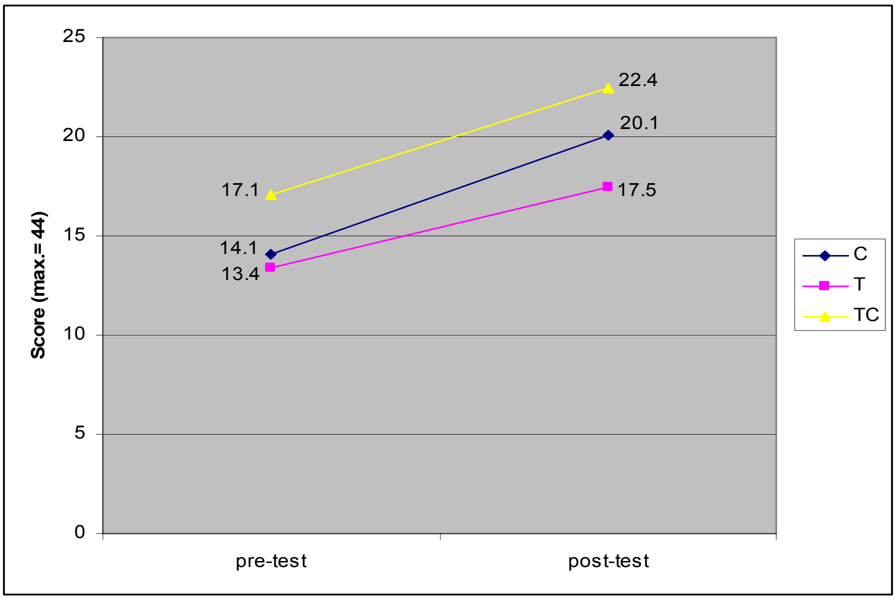


Figure 6-8. Pre- and post-test total scores of KM test.

In Figure 6-8 we can see that the differences for the total test score between three experimental conditions are not so large. A further analysis of differences in total pre- and post-test scores between experimental conditions that used the Kruskal-Wallis test, did not show any significant differences ($\chi^2_{\text{pre-total}} = 2.003$, df =2, p=.367; $\chi^2_{\text{post-total}} = .4.995$, df =2, p=.082). With this statistical test result, we could not confirm our prediction in the fifth hypothesis. The players in the three experimental conditions equally gain positive learning outcomes.

To analyse the test results in more detail, we divided the test scores into two sub-sections of the tests: (1) the KM general knowledge – multiple choice section, and (2) the KM strategic knowledge – essay case-based section. Below in Figure 6-9 the results are presented.

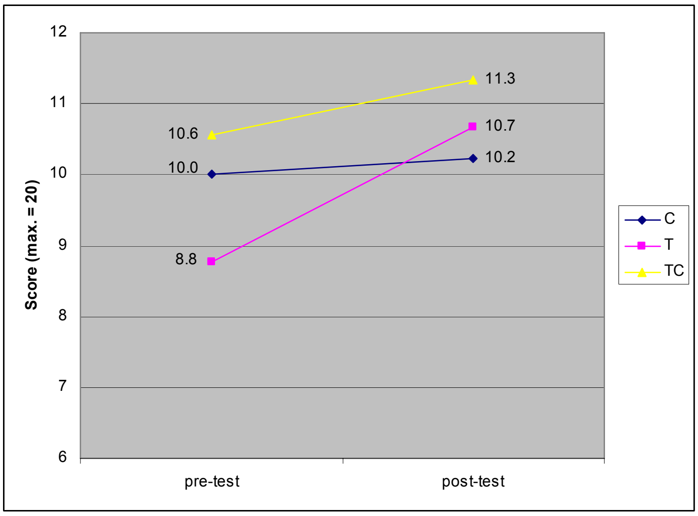


Figure 6-9. Pre- and post-test scores on KM general knowledge section (multiple-choice).

Although Figure 6-9 shows differences between pre- and post-test results of the experimental conditions, particularly for the T condition, the Kruskal-Wallis test that was done to test the differences between the pre- and post-test scores of the multiple-choice test section between the experimental conditions, found no significant differences ($\chi^2_{\text{pretestMC}}$ = 3.124, df =2, p=.210; $\chi^2_{\text{posttestMC}}$ = .439, df =2, p=.803). The Wilcoxon signed ranks test also did not confirm differences between pre- and post-test results in the multiple-choice section of the test for all conditions (z_{Ccond} = -.141, p_{Ccond} = .888; z_{Tcond} = -1.622, p_{Tcond} = .105; z_{TCcond} = -.836, p_{TCcond} = .403).

Figure 6-10 shows that the players in the C and TC conditions attained more positive learning outcomes in the test section of strategic knowledge than the players in the T condition. The same statistical procedures were carried out to test the differences shown in Figure 6-10.

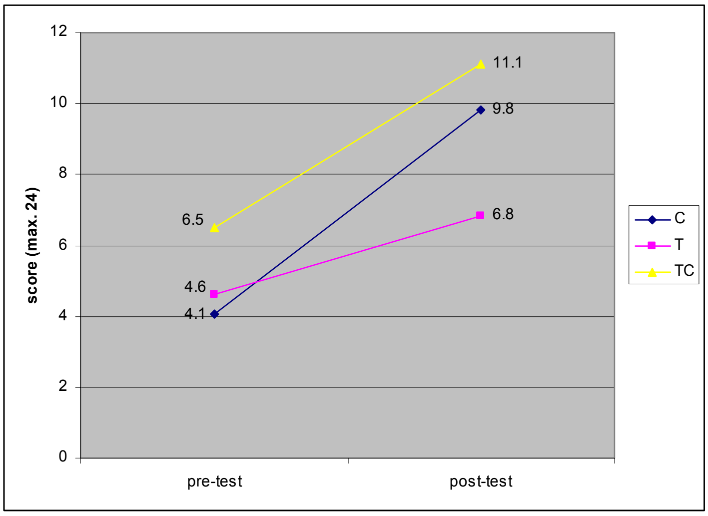


Figure 6-10. Pre- and post-test scores of KM strategic knowledge section (Essay).

The tests to compare the pre-test scores between experimental conditions from the KM strategic knowledge test section (essay case-based section) did not find a significant difference ($\chi^2_{\text{pretestCB}}$ = 3.124, df =2, p=.210). But, the statistical test on the post-test scores of this test section between experimental conditions did confirm a significant difference ($\chi^2_{\text{posttestCB}}$ = 7.616, df =2, p = .022). The Wilcoxon signed rank shows that there are significant differences between pre- and post-test scores in the case-based section between the players in the C and TC conditions (z_{Ccond} = -2.666; p_{Ccond} = .008; z_{TCcond} = -2.016; p_{TCcond} = .044). The Table 6-7, column Diff - CB^b, shows the difference between the post-test scores in the case-based test section between the players in the C and TC conditions are respectively 6.0 (s.d.= 3.8, N=9) and 5.4(s.d.= 5.1, N=9) points meaning qualitatively there is only a slight difference between them.

The overall results of the learning outcomes did not confirm our fifth hypothesis. We found that the players in all experimental conditions attained equally positive learning outcomes. There was no significant difference in the total pre- and post-test scores between experimental conditions. However, in a further analysis of the scores from the test sub-sections, it was found that there is a significant difference in learning outcomes in terms of KM strategic knowledge for the players in the C and TC conditions. It was concluded that the players in the C condition gained slightly more positive learning outcomes in the category of KM strategic knowledge than the players in the TC condition. We did not find any significant difference between the scores in the test sub-sections for the players in the T condition.

Qualitative comparison of Pre- and Post-test KM scores of the current experiment with the previous one

Comparing the result of the KM knowledge test of this experiment with the previous one was done qualitatively. This comparison was meant obtain an overall overview on the effect of the extensive preparation prior to the playing session and the modification of the KM Quest interface. We did not perform a statistical comparison to test the differences, because of the differences in the measurement tool used for KM knowledge.

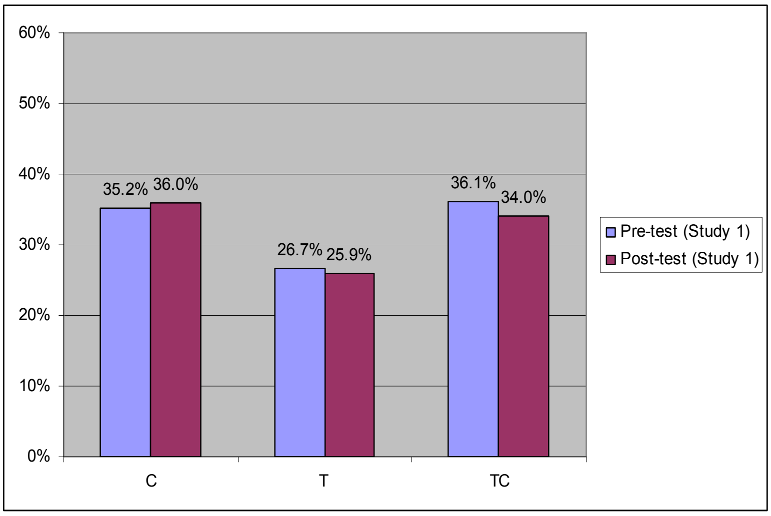


Figure 6-11. Pre- and post-test scores of the experimental conditions in Study 1.

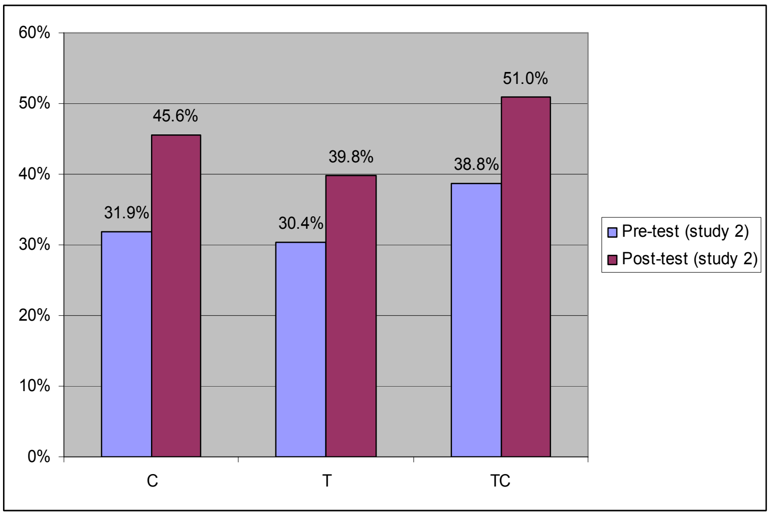


Figure 6-12. Pre- and post-test scores of the experimental conditions in Study 2.

Both Figure 6-11 and Figure 6-12 show that the qualitative differences between the pre-test scores in each experimental condition between the current and previous study are not very large, but the differences on the post test are. We concluded that the extra support in the shape of more reading materials, the extensive introduction, the instructional sessions before the playing process, and the modification of the visibility of the available chart, K_Map, and numerical table in the game environment, provide a positive effect on the overall final test scores.

6.5.8 Recapitulation of study 1 and 2: differences between the results

Summarising the overall findings, we tabulated the results from study 1 and study 2 in Table 6-8.

Table 6-8. Summary of the results from Study 1 and 2

STUDY	*Effectiveness of Communication processes*	*Quality of Intermediate outcomes of communication*	*Quantity of decision outcomes*	*Satisfaction with group decision making*	*Learning outcomes*
1	T>TC>C	TC>T>C	TC>T=C	TC=C=T	To: TC=C=T (-)
2	TC>C>T	C>T>TC	T=TC>C	TC>C>T (Ou)	To: TC=C=T (+); St: C>TC (+)

Notes: Ou= decision outcomes; To= total; St= strategic knowledge; (+)= positive result; (-)= negative result.

As can be seen from Table 6-8, the overall hypothesis for this research that the TC condition would do better than the C condition and the C condition better than the T condition on all measures, is not confirmed. It does not hold in the first nor the second study. Nonetheless, from a purely qualitative point of view of taking ranks into account, the TC condition is only strictly outranked by other conditions in three of the ten cells in Table 6-8. This at least is an indication that the TC condition is overall slightly better than the other two conditions.

Very striking are the positive overall learning outcomes in Study 2, due to better playing preparation and visibility of the visualisation support which probably led to better group decision making processes. Concerning the differences between the experimental conditions, the overall result of learning outcomes showed there was no difference between the experimental conditions, except for the result for the strategic knowledge which shows that the support of charts and schematic map only was slightly more positive than the combination of the charts, schematic map, and numerical table. This has raised our interest to analyse the differences of the overall group decision making process between Study 1 and 2 for each experimental condition.

In Table 6-9, we summarise the differences of the results between Study 1 and 2 for each experimental condition.

Table 6-9. Differences of the results of study 1 and 2 between experimental conditions.

Cond.	*Effectiveness of Communication processes*	*Quality of intermediate outcomes of communication*	*Quantity of decision outcomes*	*Satisfaction with group decision making*	*Learning outcomes*
C	improve	improve	Same	improve; Ou(2)	To: same (+); St: better (+)(1)
T	worsen	same	improve	improve; Ou(3)	To: same (+)
TC	improve	worsen	same	improve; Ou(1)	To: same (+); St: better (+)(2)

Notes: Ou= decision outcomes; To= total; St= strategic; (+)= positive result; (-)= negative result; (1)= first rank; (2)= second rank.

Table 6-9 shows that in the second study the teams in the C condition had improved effectiveness of communication process which was accompanied by improved quality of intermediate outcomes of communication processes but the same quantity of decision outcomes compared to the first study. It is slightly different if we look at the teams in the TC condition which had also improved effectiveness of communication processes but this was accompanied by a worse quality of intermediate outcomes of communication processes. As the teams in this condition had the same results as the C teams on the other measures, the question is how this can be explained. One possible explanation has to do with the validity of the measures used for the quality of intermediate outcomes. It was assumed that less time, less money and more game quarters are positive qualities, but is imaginable that given the nature of the preparations and the observed learning outcomes and the amount of available information, serious playing by itself will lead to spending more money and using more time.

The teams in the T condition could also gain positive overall learning outcomes in the second study but failed to gain strategic knowledge positively. If we look to the second row of Table 6-9, we can see that the effectiveness of communication processes of the teams in this condition was worsening, whereas the quality of the intermediate outcome of communication processes was the same. But the quantity of the decision outcomes was improved in the second study. This indicates that the positive overall learning outcomes might be related with improved quantity of decision outcomes. Thus, collaboration in the teams in the T condition, in terms of exchanging information, did not happen as effectively as in the teams of the C and TC conditions. We could interpret this as an effort in their group decision making to come up with a high quantity of outcomes to solve the main problem without having effective communication processes. In this way they still can learn, but lag in strategic knowledge behind the teams in the other conditions, because more effective communication between team members could be a prerequisite for acquiring this type of knowledge.

6.6 Conclusions

In this study we obviously found a different playing process than in the previous one. It appears that the overall playing process, in terms of sharing numerical information in group decision making processes, is richer, despite the fact that the participants in this study have a slightly lower ability to construct and interpret graphical charts.

Similar to the previous study, in this study we also predicted that: *First,* the teams, who are supported with a complete set of numerical information visual representations – the charts, the schematic map, and the numerical table, will communicate much more effectively in the group decision making process, produce the best quality of intermediate outcomes of the communication process, the highest number of decision outcomes, are much more satisfied with the decision making process, and attain more positive learning outcomes than those who are supported with either the charts and schematic map only or the numerical tables only; *Second*, the teams, who are supported with the spatial numerical information visual representations - the charts and the schematic map, will communicate more effectively in the group decision making process, produce better quality of intermediate outcomes of the communication process, a higher number of decision outcomes, are more satisfied with the decision making process, and attain more positive learning outcomes than those who are supported with the numerical tables only; *Finally*, the teams, who are supported with the symbolical numerical information visual representations - the numerical table, will communicate least effectively in the group decision making process, produce the worst intermediate outcomes of the communication process, a lowest number of decision outcomes, are least satisfied with the decision making process, and attain the least positive learning outcomes than those who are supported with the spatial numerical information and the combination of the spatial and the symbolical numerical information. The findings showed in this study, to some extent, confirm our predictions. We concluded that most of the predictions can be confirmed, but with some restrictions. Below, we elaborate our conclusion one by one.

The predicted effects of the visual representations on *the communication process of group decision making* were, to some extent, found. The foremost conclusion is about the support of charts and the schematic map or the combination of charts, schematic maps, and numerical tables on the information sharing session which leads to a relatively higher proportion of sharing interpretations of numerical information in the design phase, the choice and implement phase, and the feedback loop of the group decision making process. However, the support of the combination of charts, schematic map, and numerical tables is only slightly better than the support of charts and schematic maps only. We believed that the effect of charts and schematic map or other diagrams, combined with numerical tables in the information sharing sessions would be very crucial to achieve positive learning outcomes. However, the effect of the numerical table only on the effectiveness of the communication process were more negative than for the other visual representations. The representation of the numerical information in the table does not seem to stimulate players to exchange the numerical information in the decision phases, which leads to an unbalanced profile of communication processes over the decision making phases, particularly in terms of limited information exchange in the feedback loop of the decision making process. Additionally, we concluded that the support of the numerical table seems less positive for eliciting a large number of deep cognitive interpretations of multiple numerical information and integrating the numerical information with other information resource from the game environment, compared to the other visual representations.

In terms of *the intermediate outcomes of the communication process*, we conclude that the charts and schematic map supported the teams to produce intermediate outcomes more effectively than the numerical table, or a combination of charts, schematic map, and numerical table. The visual representation of the charts and the schematic map seems to support teams to play slightly fewer game quarters, but using the shortest time and an intermediate amount of money. The representation of the numerical information in the charts and the schematic map tends to support teams to play fewer game quarters but with a shorter time and using the least amount of money. The representation of the numerical table in combination with the charts, schematic map, and the numerical table supports the teams to play an almost equal number of game quarters as in the teams who are supported with the numerical table, but using an intermediate amount of time, and using most of the budget.

In terms of *the quantity of the decision outcomes*, we conclude that the support of the numerical table and the combination of charts, schematic map, and the numerical table led to an almost similar amount of decision outcomes, but slightly larger than with the support of the charts and schematic map only.

It should be understood that the above conclusions are made based on non-statistical comparisons, due to a small sample size. As a consequence, the conclusions are interpretative and have a limited value for generalisation.

At this point, we observed that in the overall playing session, the effectiveness of the communication processes did not always led unequivocally to better intermediate outcomes of the communication process and a higher quantity of decision outcomes. Surprisingly, despite having limitations in information exchange in the decision making process, the support of the numerical table could produce the same quantity of decision outcomes as the support of the combination of charts, schematic map, and the numerical table, which was slightly higher than the support of the charts and schematic map only.

Further, regarding *the satisfaction with group decision making processes* in the playing session, we conclude that the satisfaction of the players with decision making processes did not always concord with what could be seen in the actual situation. Although there were differences in the effects of the visual representation on the effectiveness of the communication process, players tend to judge the decision making process to be equally satisfactory. However, for one or another reason, the players who are supported with the numerical table tend to show slightly less satisfaction with the decision outcomes. It indicates a high level of players' expectation about the appropriateness of the decision outcomes in the overall playing process.

Concerning the overall learning outcomes in each experimental condition, we conclude that the players in all experimental conditions attained equally positive learning outcomes. We did not find that players in one of the conditions learn better than others. This finding is interesting because despite having the least effective communication processes, the teams who were supported with only the numerical table are still able to attain positive learning outcomes. This implies that the role of charts and diagrams in fostering positive learning outcomes is less than predicted. However, the most interesting finding was found while examining the differences between the test results from the section of the knowledge test that measures KM strategic knowledge. We conclude that the effect of charts and schematic map on the effectiveness of the communication process tends to coincide with more positive learning outcomes in acquiring strategic knowledge than the support of the combination of charts, schematic map, and the numerical table. The difference in the visual information did not led to differences in the overall learning outcomes but did in attaining positive learning outcomes for strategic knowledge. In this case we conclude that charts and schematic maps are much better than the combination of charts, schematic map, and numerical table. The numerical table does not support players to attain this type of knowledge after playing the game as well as the representations in the other two conditions do. We conclude that, as expected, to teach KM strategic decision making, KM Quest has shown its ability to teach this type of knowledge with the support of charts and schematic map. However, in general we felt that qualitatively, the overall learning outcomes after playing were still low in this experiment. We still believe that the effect of the playing process in this experiment is still not as optimal as we expected. More research must be done to support the overall playing process in order to attain more positive learning outcomes in the future.

Regarding the cost-effectiveness of the support of the combination of charts, schematic maps, and numerical tables, we believed that from the design perspective, combining charts, schematic map, and numerical tables would lead to a perfectly suitable information representation. However, this study showed this not to be clearly evident. We conclude that the support of the combination of the visual representations does influence the communication process and the learning outcomes almost equally well as with the support of charts and schematic map only. Thus, in terms of cost effectiveness the combination of charts, schematic maps, and numerical tables is perceived as less optimal than using charts and schematic map only.

Summarising, we conclude that the support of the spatial versus symbolic visual numerical information does influence the effectiveness of the communication process in group decision making but does not lead to more satisfaction with group decision making and learning outcomes from Figure 5-1.

Additionally, we found that the level of prior KM knowledge of the players in this study was not as high as expected after having an extensive preparation session and extra reading materials. Compared with the level of the prior knowledge from the previous study, the result is qualitatively almost equal. However, the overall learning outcomes found in this study were significantly more positive in all experimental conditions. This finding is very interesting because in the previous chapter, we suspected that the low level of prior knowledge about KM would in many ways disturb the way the players will perform their actions and communicate meaningfully. However, this did not hold in this study. We concluded that first, the level of prior knowledge about KM does not directly influence the effectiveness of the information exchange process in communication, and secondly the extensive preparations that were given prior to the gaming session in this study are not able to increase the level of prior knowledge about KM directly but possibly provide prior knowledge about the game - knowledge about how to play and to communicate in the playing process. Nevertheless, we further suspect that the extensive preparation alone could not bring any effect without a proper design of the game environment, particularly the visual representation as the most important information source in the playing and communicating process. Thus, the combination of the extensive preparation and playing with better visibility of numerical information leads to better playing and communicating in the course of the game and learning outcomes at the end.

Another issue that arose while comparing the first study with the second one is that the group decision making satisfaction was always high. There are two reasons that may explain this result. One, the validity of the questionnaire to measure players’ judgment of the group decision making correctly may be questioned, possibly because not all dimensions that could be relevant for this particular group decision making situation were covered. Second, sometimes there is a cognitive dissonance effect: after spending an entire day on playing KM Quest it could be difficult to admit that you did not like it at all.

Finally, it could be that the role of group satisfaction with decision outcomes is less important, or even totally absent for leading to positive learning outcomes. The latter may lead to a modification of Figure 5-1, the link between decision outcomes and learning outcomes is probably not directly mediated by satisfaction. We point this as an interesting issue to be investigated in the future.

7 Conclusion

7.1 Conclusion

In this dissertation learning KM in collaboration provides not only a new domain to the players but also knowledge intensive activities. It is believed that learning KM in collaboration supports managers to build a new way of thinking and interacting to deal with daily activities in decision-centred work. We also know that the popularity of using narrow-bandwidth computer mediated communication in solving daily tasks by managers in organisations, particularly for those who are distributed geographically, is increasing. Several risks and benefits of the use of narrow-bandwidth computer mediated communication have been theoretically discussed and elaborated in Chapter 2. One might imagine that decision-centred work and the use of narrow-bandwidth communication tools by managers to accomplish knowledge intensive tasks will become more and more ubiquitous. Therefore, it is expected that the contribution of KM as not only a new domain but also as representing knowledge intensive activities in computer-mediated collaboration between managers in organisations, adds to the value of learning and communicating collaboratively in organisations. Our theoretical review shows that the need of learning KM in collaboration is not only demanding, but also useful and challenging to be provided to organisations. As we know, achieving learning KM in collaboration is jeopardized by the narrowness of the communication medium itself. In many ways communicating with narrow bandwidth mediated communication tools is complex and potentially adds extra tasks to the communication process of the managers. However, on the other hand, having face-to-face meetings are not only becoming less frequent, but are also not cost-effective regarding the distance between members of the team. This overall situation is seen to be a very promising and challenging issue to be further supported and investigated.

The main topic of this dissertation is on supporting information exchanges between people in narrow-bandwidth computer mediated communication while they perform group problem solving and decision-making collaboratively in knowledge-intensive tasks. Visualisation support is believed to enhance the effectiveness of communication processes when using narrow-bandwidth tools, such as text-based chatting tools, and lead to better solutions of the problem. The research conducted in this book is focused on whether the support of visualisation by means of *spatial* numerical representations (charts, schematic maps or diagrams), *symbolical* numerical representations (numerical tables) and a *combination* of both, will elicit differences in the nature of the communication between learners in collaborative decision making and problem solving processes and the learning outcomes. Generally speaking, the basic hypothesis was that the *combined* support will lead to better results than the *spatial* one, and the *spatial* one to better results than *symbolic* support. One explorative study and two experimental studies were done to investigate this. Generally, the results of these studies, at one hand, confirm some effects of the visualisation support on the communication processes in decision making and on learning outcomes. On the other hand they also open many novel issues in supporting communication processes with visualisation in decision making in text-based computer mediated communication.

In the preliminary study, we did not try to find differences in the effects of the visualisation on the communication process, but rather tried to verify if (1) our visualisation design is acceptable and useful in the playing process, and if (2) the numerical information is the important and relevant information in the communication process to solve the problem. After this study, we had the impression that, first, our visual design needs only minor modifications and was judged as valuable information support in the playing process. Second, the communication process to exchange important and relevant (numerical) information taken from the game indicators to solve the problem is indeed the central issue of communication during the collaboration process. Although the study was done in a limited game environment, the result showed how the players interacted and exchanged the interpretation of the numerical information to solve the problem in the communication process. From the perspective of the effectiveness of communication processes, we observed that although the text-based chat tools are limited in mediating information sharing, the players were still able to exchange their *cognitive* interpretation of the numerical information. However the communication process was done only to share the result of the cognitive numerical interpretation of the spatial numerical representations or symbolical numerical representations. An attempt to *comprehend* symbols or icons from charts and diagrams, or numerical information from the table was not found. We found that the overall communication was restricted and did not contain much individual understanding about the domain being learned and other information resources available in the game environment. However, this communication limitation is understandable because the game environment lacks instructional support and interactivity as is present in other computer-based games.

In the other two studies, the playing process became more complex. The real KM Quest environment and its instructional support, and the communication tools stimulated the players to get involved with group decision making and problem solving iteratively during playing sessions. After conducting both studies, we become more convinced that the centrality of the information exchange in the communication process to solve the main problem depends on a condition where participants access, interpret, and share relevant information. Information exchange interaction in text-based communication processes with the support of visualisation has a function to inspire players and synchronise players' knowledge in obtaining more information, developing ideas, making a selection from a set of solutions, and providing feedback on past decisions. These functions bind players in a team to be knowledgeable in the process of solving the problem collaboratively by exchanging information such as numerical information from the game indicators. However, differences in the way numerical information is presented (spatial, symbolic, combined), are hypothesised to influence the way players exchange information in the communication process.

In this chapter, the conclusions about these effects are presented in the following order: (1) the effect of different visualisations on the effectiveness of group decision making processes, (2) the effect of different visualisations on participants' satisfaction with group decision making, and (3) the effect of different visualisations on the learning outcomes. One should keep in mind that the studies done in this dissertation cover only synchronous text-based computer mediated communication. It is not our intention to generalise our findings to any asynchronous communication tools or other types of communication media.

7.1.1 The effect of different visualisations on the effectiveness of group decision making processes.

The effectiveness of group decision making processes in this dissertation is evaluated on three dimensions: (1) effectiveness of communication processes; (2) quality of intermediate outcomes of communication processes; and (3) quantity of the decision outcomes. Below we describe our conclusion based for each of these categories. It was predicted that the support of *combination* of spatial and symbolical numerical representations would lead to a more effective process of group decision making in the three abovementioned dimensions, compared to the support of either *spatial* or *symbolical* numerical representations only. Additionally, it was also predicted that the support of *spatial* numerical representations only would lead to a more effective process of group decision making in the three dimensions, compared to the support of *symbolical* numerical representations. However, these predictions could not be fully confirmed.

We conclude that our strategy to support the information sharing sessions with *spatial* numerical representation indeed influences the effectiveness of the communication process of group decision making mediated by narrow-bandwidth CMC. However this only holds under the condition that players are aware of the complexity of playing and interacting and also proper accessibility of the visualisation support in the system. To realise this condition, a substantial preparation about the game environment and the domain being learned, and clear visibility of the available visualisation support must be achieved *before* the playing process. On the other hand, the strategy to support the information sharing sessions with *symbolical* numerical representations only, does not effectively influence the effectiveness of the communication process, even if the players have been prepared and the visibility of the numerical table is improved. We found that the support of *symbolical* numerical representations may be effectively stimulating players to share numerical information only, when participants play the game without a serious intention to learn or master the domain but only for creating awareness about the domain.

An interesting point that might be further investigated is the tendency of teams who were supported with the *symbolical* numerical representations, to participate in information exchange processes by using, on average, much more message lines but shorter sentences compared to the teams who were supported with spatial numerical representations. We found this finding consistently in both experimental studies. Two explanations were put forward whether this tendency occurred due to the complexity of the numerical information in tables which leads to a high conversation load or whether this finding will be consistently found other studies.

Moreover, we conclude that the differences between the nature of visual representations lead to differences in the effectiveness of information sharing in the feedback loop of the decision making phases, and sharing of multiple game indicator interpretations when sharing numerical information. It is found that *symbolical* numerical representations seem not to effectively stimulate this process. In the second experimental study, the support of charts and diagrams was found to be effective in the overall communication process in the decision making process. This is evidence that players who are supported with *spatial* numerical representations will be not too focused on only selecting the solution but also on deliberately exchanging information, on obtaining more information, on developing their ideas, and even on making a selection of solutions based on the information exchanged. The most important finding is that the support of *spatial* numerical representations tend to stimulate the feedback loop of the decision making process. This may lead to positive learning outcomes of strategic knowledge. We found almost similar findings for the teams who were supported with a *combination* of spatial and symbolical numerical representations. However, this conclusion is tentative, because the evidence did not show noticeable differences from when the players were supported by spatial numerical representations only. The *combination* of spatial and symbolical numerical representations also tends to slightly stimulate sharing deeper cognitive interpretations of patterns of numerical information, such as a subjective evaluation of a trend. However, the difference between them was found to be not very large.

An effect of the differences of visual representations on the quality of intermediate outcomes of communication processes was also found. The *symbolical* numerical representation does not support players to achieve a high quality of intermediate outcomes of communication processes. In the second experimental study, even though the preparation and the visibility of visualisation support in the game environment was better, the quality of the intermediate outcomes of the communication process stays in between the quality of the other visual representations and the quality in the first study. Contrary to this, the effect of *spatial* numerical representation is positive to achieve a high quality of intermediate outcomes of communication processes if the preparation and visibility of visualisation support are better. Surprisingly, the effect of the *combination* of spatial and symbolical numerical representation on the quality of intermediate outcomes when combined with better preparation and visibility of visualisation support in the game environment in the second study, is negative compared to the first study. We believe that the high information abstraction level of *spatial* numerical representations is better for achieving a higher quality of intermediate outcomes than the low information abstraction level of a *symbolical* numerical representation. One could imagine that to come up with high quality intermediate outcomes of communication processes, such as the use of time and expenditure or budget, and the number of problems solved, during complex interactions in narrow bandwidth decision making processes, can be more easily achieved with the support of rather general information abstractions such as depicted by icons and other perceptual symbols, than by detailed inspection of precise numbers in a table.

Quantity of decision outcomes can be understood as the result of the effectiveness of the information exchange and the quality of intermediate outcomes of the communication process in the group decision making process. We found that the effect of *spatial* numerical representations and the *combination* of spatial and symbolical numerical representation do not always lead to a larger number of decision outcomes, compared to the *symbolical* numerical information. Although in the second study the preparation prior to the playing phase and visibility of visualisation support was better, this influences the teams who were supported with *symbolical* numerical representation. In such a situation, symbolical numerical information seems to produce an equal quantity of decision outcomes as combined representations, which in turn are higher than with spatial numerical representations only. We think this could occur due to difficulties for the players to asses their past decision outcomes regarding the changes in the game indicators. Because of the effects of the decision can not be easily understood from the numerical information, an attractive solution to this problem is to produce as much decision outcomes as possible. We see this as a kind of trial-and-error mechanism triggered by difficulties to understand the relationship between symbolical numerical information contained in numerical tables and consequences of past decisions.

Summarising the above conclusions, we believe that the different results of the first and the second study confirm the effects of different visualisation support types (spatial versus symbolical numerical representations) on the effectiveness of communication processes in group decision making processes. Another crucial and key factor to add to this conclusion is a condition where participants purposefully access the source of numerical information representations, namely the numerical table, diagrams, and charts. Although in this dissertation we could not show clear evidence that directly links differences between visual representations to better preparation and visibility of visualisation support and accessing of visualisation support, we still believe that accessing visualisation support is a necessity to be able to effectively inspire participants to share high quality numerical information with the support of visual representations when solving problems collaboratively.

7.1.2 The effect of the visualisation on players' satisfaction with group decision making

The predicted effect of the visualisation on the players' satisfaction with group decision making was that the *combination* of spatial and symbolical numerical representations would be better than either *spatial* or *symbolical* numerical representations only. *Spatial* numerical representation only would provide a better effect on the players' satisfaction with group decision making, compared to *symbolical* numerical representations only. The satisfaction with decision making is measured on 3 dimensions: satisfaction with the decision process, decision outcomes, and system support or facilitation.

Although it is stated in Chapter 5 that differences in visual numerical representations will influence the effectiveness of the group decision making process and may be directly influence players' satisfaction with group decision making, the results of the first and second study are different.

In the first study, the satisfaction of the players was equally high in all dimensions. There were no significant differences between the players in one or more conditions. But in the second study the result was slightly different. The players in the teams who were supported with the *combination* of both spatial and symbolical numerical representations were more satisfied with the decision outcomes than those who were supported with *spatial* or *symbolical* numerical representations only. However, the players who were supported with *spatial* numerical representations were more satisfied than those who were supported with *symbolical* numerical representation only. The players in each condition were moderately satisfied with the decision outcomes, but the difference is significant. The differences of the satisfaction on the two other dimensions, decision process and system support or facilitation, between players in each experimental condition are not statistically significant. The players were equally satisfied with these two other dimension.

We conclude that differences in the nature of visualisation of numerical information may only slightly influence players' satisfaction with group decision making, particularly on the dimension of satisfaction with decision outcomes. There are two possible explanations for this.

First, when evaluating and observing players' communication processes they were not as optimal as theoretically expected. We do have the impression from our direct observations during the playing process and the analysis of the chatting process, that the actual process of text-based mediated communication in decision making was rather troublesome for the players. It seems to us also that there is a discrepancy between what is actually experienced by the players in group decision making in the playing process, and what was reported subjectively in the questionnaire. Because of these, we could say that players' judgments about satisfaction with the experience in group decision making in the playing session may not be measured correctly or was not reported correctly by the players. This can be either due to the fact that the test missed some evaluative aspects that are particularly relevant for this specific decision making context, or simply to reducing cognitive dissonance after playing for a prolonged period.

Second, when we analysed the result of the second study carefully, we have the impression that the effect of the visualisation support on the effectiveness of the communication process seems to be similar to the results of the players' satisfaction with the decision outcomes. We think that the influence of the type of visualisation support, particularly ones that have *spatial* elements, on the cognitive numerical interpretation of the decision outcomes to some extent exist, particularly when players share the interpretation of the changes of the value of game indicators in the communication process. The *spatial* numerical representation tends to be comprehended cognitively in a process to recognise the qualitative meaning of the perceptual symbols or icons that represent the change of the numerical information over time. In this case, the length of bars, the height of columns, or a gradient of lines elicit a spontaneous and fixed reference for a cognitive understanding about the qualitative changes for the individual team members as well as for the team as a whole. In this way a link between interventions and outcomes can be established in an easier way, leading to more satisfaction with the decision outcomes. On the other hand, changes in numerical information in *symbolical* numerical representations tend to elicit a more detailed understanding of the precise numerical changes which must be interpreted first cognitively by a team member by considering the differences in measurement units or dimensions of the numbers, and next by the team as a whole in a narrow-bandwidth communication context. This makes linking interventions and outcomes more difficult, leading to less satisfaction with the decision outcomes. This is probably even more marked when we take into account that the teams who were supported with tables only, submitted the largest number of interventions, maybe because the trial-and-error approach was triggered by a lack of meaningful interpretation of the decision outcomes.

These explanations are interesting starting points for future research in similar areas.

7.1.3 The effect of the visualisation on the learning outcomes

It was predicted that the effect of the visualisation support by means of a combination of spatial and symbolical numerical representation would lead to better learning outcomes, compared to the effect of either spatial or symbolical numerical representations only. We found that the result of both experimental studies did not confirm the prediction.

It is quite interesting to see that in the first study, we found that there were no positive learning outcomes in all experimental conditions. The support of the visualisation on the overall playing process could not realise the intentions of the visual design at all. However, in the second study, although the learning outcomes were measured with a different test, we found equally positive learning outcomes for each experimental condition. Additionally, the total score of the post-test is much higher in the second study, but we found that it was not as high as expected.

Regarding the difference in the learning outcomes between the first and second study, it is concluded that the effectiveness of the communication process in group decision making could have played a very important role. In general, the participation in communication processes in the second study is much higher than the first one. It was already an indication that group decision making in the second study was done more deliberately.

Nevertheless, in a further analysis, we found that the *spatial* numerical representations tend to slightly support a better acquisition of strategic knowledge, solving KM problems strategically, than the *combination* of spatial and symbolical numerical representations. It is concluded that regarding cost-effectiveness, the use of a combination of spatial and symbolical numerical representations is less effective compared to the spatial or symbolical ones. We did not find any clues that the support of symbolical numerical representations would lead to a better acquisition of KM strategic knowledge.

Furthermore, we conclude that the support of the *symbolical* numerical representation can not be discarded for attaining positive learning outcomes. Whilst we could not specifically found a finding that supports the acquisition of a particular type of knowledge, generally we think that the support of symbolical numbers in numerical tables is equally positive compared to the *spatial* numerical representation only or even in a *combination* of them. From a design perspective, the contribution of *symbolical* numerical representations to attain learning outcomes is fairly positive. Thus, we would like to emphasise the effectiveness of the support of a numerical table in individual learning processes. However, one can imagine that in a condition of overall deliberate collaborative learning processes, the support by numerical tables is less positive than the support of charts and diagrams. When in these processes the participants are still not able to become involved deliberately, such as in the early phases of collaborative learning, for creating awareness about the domain being learned, the support of numerical information may positively stimulate information exchanges in the communication process.

Another issue that arose while comparing the first and the second study is the role of prior knowledge. While summarising the first study, it was predicted that the low prior knowledge about KM may prevent the playing process to contribute to positive learning outcomes. However, after conducting the second study, this prediction must be dropped because we found also a comparable low prior knowledge of KM in the second study. Nonetheless, the players in the second study were able to attain significant positive learning outcomes, no matter what the type of visualisation support is. We believe that the blending of extra preparation and reading material that was given in the second study and also the modification of the visibility of available visualisation support – order of the game indicators and visualisation packages, provided better prior knowledge about the *playing* situation and conditions prior to the playing process, leading to better playing sessions in the game environment. These are believed to create constructive learning and meaningful interaction processes in the playing session to learn the domain. This suggests that better preparation, extra reading materials, and better visibility of visualisation supports may increase the prior knowledge about the playing process and the game environment and consequently make playing the game easier and more motivating for novice participants.

Learning KM in collaboration as discussed in the earlier chapters is indeed a complex and difficult process but can provide meaningful learning opportunities. In general, learning KM in collaboration does not only introduces KM as an ill-defined domain, but at the same time attracts participants to get involved in actual KM related problems that they might encounter in decision-centred work. In particular the complexity of collaborative communication to understand the problem, the sharing of their knowledge to obtain more information, to develop their ideas, and to decide on solutions for the problems, all in a condition that is mediated by a narrow-bandwidth communication channel. In the two experimental studies, we observed that to become involved in this complex situation is a real challenge for the participants.

7.1.4 Lessons-learned

We think that our strategy to support text-based CMC processes with either spatial or symbolical numerical representations or a combination of both to display numerical information about the game indicators, is appropriate and equally useful for the players to solve the problems collaboratively and learn the domain. However, based on the above conclusions, the complexity of the text-based communication process can not be directly supported with visual representations only, as we initially thought. We suspect that a more effective support of visualisation for information exchange must fulfil some (pre-) conditions. For instance, a better playing preparation to increase the readiness of players to deliberately interact in a complex playing session, and a certain level of prior knowledge, particularly prior knowledge about the game environment.

Concerning the interaction between players in the overall decision making process, we came to the general conclusion that the nature of the communication process in terms of information sharing to integrate interaction and communication between remote participants, such as in geographically distributed teams, is more than just presenting high quality information, such as the visualisation of numerical information. The need for better playing preparation and visibility of available visualisation adds to the effectiveness of the visualisation support for the communication processes.

However, creating awareness with participants to exchange the relevant information in a team, apparently not naturally corresponds to designing the quality of information representations. Well-designed visualisation supports maybe achieved by envisioning (numerical) information that fit the cognitive process, but directing the observer to perceive the well-designed representation may not correspond to the intentions of the design. In other words, design may facilitate access to information, but does not automatically implies that the accessed information will be used in a decision making process. We believe that the tendency of observers to ignore available information is an inbuilt property of complex and difficult communication processes such as can occur in narrow-bandwidth group decision making and probably in other knowledge intensive activities also.

We conclude that any efforts in designing high quality visual information must be combined with other efforts to make viewers aware of and willing to comprehend and use the visual cues. Solving a problem collaboratively with the support of visualisation is only effective if participants are also enticed or challenged to deliberately share their thoughts in relation with the interpretation of the visual cues.

The difference in the nature of the visualisation of numerical information, *spatial* versus *symbolical* numerical representations by means of charts/diagrams versus numerical tables, leads to a better awareness of information exchange in communication. In this sense, we expect that the support of the visualisation by means of charts/diagrams will potentially stimulate players to effectively ground the problem being solved during the course of communication in group decision making processes.

Finally, as other research on visualisation has found, in this study it was also found that the support of different types of visual representations is equally effective to attain positive learning outcomes. But differences between types of visualisation do influence (1) the acquisition of strategic knowledge and (2) the effectiveness of communication processes during decision making using text-based computer mediated communication tools. We adopt the caveat that the function of visualisation to support this kind of communication process in decision making always depends on how deliberately the visualisation supports themselves are perceived and used in the communication process. If collaboration is preferred in the communication during decision making processes, graphs and diagrams appear to stimulate information sharing. Numerical tables are not much less useful than charts and/or diagrams to support participants to attain positive learning outcomes but they are found to be less supportive to elicit effective information exchange in communication processes. The combination of charts, diagrams, and numerical table, is not most preferred to support either collaborative communication processes or to attain positive learning outcomes because of being less cost effective and the risk of a redundancy of information resources.

Overall, the results from two experimental studies directly show evidence that a learning process of KM in collaboration is not easy to achieve and the learning outcomes are not always positive, particularly for our players who are classified as novices in KM and KM Quest. We still think that the process of communication in learning KM in collaboration by novice participants must be further investigated to provide more data on how to effectively support such complex communicative interactions.

7.2 Future directions

7.2.1 Simulation and gaming for collaborative learning of KM

The potential of simulation and gaming to mediate the learning and work process jointly in learning organisations is substantial. In our research, although we did not claim that simulation and gaming is the only solution for learning, we would suggest that the situation provided by simulation and gaming, such as in KM Quest, really reflects the complexities and similarities of decision-centred type of jobs in reality, but in a totally safe environment where managers can try out or exercise their communication process in making decision as they wish.

We concluded that simulation and gaming with extensions with communication tools, provide a rich environment for the managers to interact and communicate in exercising their decision making process collaboratively. By getting involved in this process, we are optimistic that learning processes can be located in a broader organisational and geographical coverage. Obviously, we are aware that integration of playing, communicating, learning, and working is not easy to achieve. Therefore, the facilitation of the simulation and gaming process in organisational learning always needs extra attention, from a practical as well as a methodological perspective. Moreover, the role of visualisation to provide feedback during the playing process is seen as the main function for well-designed visual objects in a game system. We expect to see a further application of well-designed visualisations in other types of simulation games in business and management training.

One important aspect that was not addressed in the studies of this dissertation is the debriefing session. We did not provide our players with a debriefing session in our experiment purposely, because we did not focus on finding the effects of a debriefing session on the playing process. But after conducting two experiments, we observed that the demand for a debriefing session is actually high during and after playing and the function of a debriefing session is crucial, particularly for a game which has rather free-rules such as KM Quest. The opportunities for reflection that will be provided by a debriefing session in the game are as important as the playing session itself. We feel that the debriefing process is not only important but also necessary to increase the value of gaming and simulation for internalising and sustaining the learning outcomes.

For further research, we are almost sure that if the debriefing session is included in the playing session, the communication process and the learning outcomes, afterward, will be much more optimal. However, it is a real challenge to, first, create a proper procedure for the debriefing session in KM Quest, and second to include the debriefing session in the collaborative learning process in the game system. We look forward to opportunities to implement the debriefing session in the playing process and test the results.

7.2.2 Replicating the study and automated text analysis

Although we found some evidence of the effects of differences in visual representations on the communication process and the learning outcomes, the sample size we used was rather small, which leads to rather high standard deviations and does not allow formal statistical analysis. Due to this sample size, the results of this study are rather difficult to generalise to similar situations. Replication of studies with a larger sample seems to be the most preferred research strategy in the future. However, as the focus of the research is on communication, it also reminds us that to be able to observe the communication processes, the research challenge is not on how to obtain the data but how to objectively analyse the data. Analysing chatting session is a very labour intensive activity. The time and energy spent to extract the research data from communication processes is the challenging research issue in applied communication science and collaborative learning processes in applied educational science.

As we expected, the function of the chatting tool to mediate communication in learning processes can be seen as relatively beneficial if supported with visualisation of the numerical information. Although we did not compare the use of the chatting tools with other types of communication tools, we obtained the impression that the ability of the chat tools to mediate the learning process is just good enough to synchronously balance the information to update and share participants' knowledge during the playing process. Generally we found that the players in our experimental studies tend to use, on average, short messages, meaning that the communication process involves only simple messages. We think that the combination of the text-based chat tools in a shared environment, such as KM Quest, is cost effective to attain intended learning outcomes.

We would like to highlight the need for and the potential use of automated text-based communication analysis for similar studies. The use of automated corpus analysis is probably the most preferred one, despite its vulnerability for language used by non-native speakers. If this can be done, the ongoing chatting sessions can be easily monitored by the system in real time during the playing sessions and hence an intelligence tutoring facility in the game system could be implemented. We look forward to see a further development of intelligence tutoring systems in instructional games such as KM Quest.

Another type of research that can be done is to investigate the effect of visualisation on the asynchronous communication process while playing KM Quest and the learning outcomes afterward. Based on our experience in conducting the playing session, the asynchronous communication session may be beneficial to increase learning outcomes and retention of knowledge about the domain, particularly if it is combined with the debriefing session. However, we think this would be a challenging research effort because it needs a continuous longitudinal research type which requires more playing preparations and maintenance.

Finally, the assumption we used in the experiments was that novice (student) participants in the KM Quest environment are comparable with managers who are new to KM and decision-centred work. Of course we are aware of the limitation of this type of research. We would suggest that research in the future will try to use a sample of managers in organisations and implement KM Quest as a training tool in organisations. We look forward to see a comparison of the current result with the ones obtained in such a setting.

7.2.3 Sequence of the decision making phases

While analysing the chatting sessions, we used the content of chatting session to segment the communication process in chatting episodes, but this does not takes into account the process of communication by means of the sequence of one communication state to the next state in performing communication (sub-)tasks and reaching the goals at the end of the process. We think that, in addition to the corpus analysis, a sequence analysis of the communication states – represented by a corpus, might be done to further analyse the decision making process in text-based communication. We suggest sequence analysis of the chatting states because when analysing patterns of communication over the decision making phases, the content of conversations provides only information about "what" has been discussed in a particular phase but it does not say anything about "how" the communication process changes over the phases. The sequential pattern of communication over the decision making phases would be the next challenge in researching decision making processes.

We believe if this can be done, the probability of sequential changes from phase to phase can be observed. Hence, it will create a significant number of observation units of the communication process. More detailed data are available and more advance statistical test, such as factor analysis and concordance analysis can be done. This will solve the problem of dealing with a small sample of participants in this kind of research.

7.2.4 Expanding visualisation support

The results of the research point to the potential function of visualisation in the communication and learning process, which means that the use of visualisation can be further developed particularly in the KM Quest system or in other gaming systems in general. We would suggest visualising the use of the budget over time, the number of game interventions submitted over time, and the use of time itself in graphical charts as a feedback for the group playing activities. By visualising these indicators, the quality of intermediate outcomes is expected to be better monitorable. We think that it will potentially increase the effectiveness of communication processes, add to the meaning of a playing session, provide opportunities for reflections, and create players' awareness of playing activities and learning processes. It is also believed to provide positive effects for the players to keep monitoring their communication processes, intermediate communication outcomes, and also as feedback cues in the debriefing session after playing.

Another suggestion to improve visualisation is displaying the results of the "setting objective" task (see Figure 2-1) or targeted improvement of certain sets of game indicators in the charts. We think that visualising the strived for improvement of certain sets of game indicators in the charts will not only provide more feedback but also force players to think more actively about the interrelationships of the indicators in terms of understanding the behaviour of the underlying business model.

8 References

Ainsworth, S. E., Bibby, P. A., & Wood, D. J. (1997). Information technology and multiple representations: New opportunities - new problems. *Journal of Information Technology for Teacher Education, 6*(1).

Argote, L., & Ingram, P. (2000). Knowledge transfer: A basis of competitive advantage in firm. *Organizational behavior and human decision processes, 82*(1), 150-169.

Asahi, T., Turo, D., & Shneiderman, B. (1995). Using treemaps to visualize the analytic hierarchy process. *Information Systems, 6*(4), 357-375.

Asakawa, T., & Gilbert, N. (2003). Synthesizing experiences: Lessons to be learned from internet-mediated simulation games. *Simulation & Gaming, 34*(1).

Baker, R. S., Corbett, A. T., & Koedinger, K. R. (2001). Toward a model of learning data representations. In *Proceeding of the 23rd Conference of the Cognitive Science Society*.

Bertin, J. (1983). *Semiology of graphics: Diagrams, network, maps* (W. J. Berg, Trans.). Wisconsin: The University of Wisconsin Press.

Boisot, M. H. (1998). *Knowledge assets: Securing competitive advantage in the information economy*. New York: Oxford University Press.

Boland, R. J., Jr., Maheshwarei, A. K., Te'eni, D., Schwartz, D. G., & Tenkasi, R. V. (1992). Sharing perspective in distributed decision making. In *CSCW 92 proceedings*. ACM.

Bordia, P. (1997). Face-to-face versus computer-mediated communication: A synthesis of the experimental literature. *The Journal of Business Communication, 43*(1), 99-120.

Bowen, G. M., Roth, W.-M., & McGinn, M. K. (1999a). Interpretation of graph by university biology students and practicing scientists: Toward a social practice view of scientific representation practices. *Journal of Research in Science Teaching, 36*(9), 1020-1043.

Bowen, G. M., Roth, W.-M., & McGinn, M. K. (1999b). Interpretation of graphs by university biology students and practicing scientists: Toward a social practice view of scientific representation practices. *Journal of Research in Science Teaching, 36*(9), 1020-1043.

Braden, R. A. (1996). Visual literacy. In D. H. Jonassen (Ed.), *Handbook of research for educational communications & technology*. London: Prentice Hall International.

Briggs, R. O., & Vreede, G. J. (1997). Measuring satisfaction in GSS meetings. In K. Kumar & J. I. DeGross (Eds.), *Proceedings of the 18th International Conference on Information System* (pp. 483-484). Atlanta.

Brodlie, K. W., Carpenter, L. A., Earnshaw, R. A., Gallop, J. R., Hubbold, R. J., Mumford, A. M., et al. (Eds.). (1992). *Scientific visualization: Techniques and applications*. Berlin Heidelberg: Springer-Verlag.

Burn, J. C., Okey, J. R., & Wise, K. C. (1985). Development of an integrated process skill test: Tips II. *Journal of Research in Science Teaching, 22*, 169-177.

Carson, J. R. (1969). Business game: A technique for teaching decision making. In R. G. Graham & C. F. Gray (Eds.), *Business games handbook*. American Management Associations Inc.

Carswell, C. M. (1992). Reading graphs: Interactions of processing requirements and stimulus structure. In B. Burns (Ed.), *Percepts, concepts and categories* (pp. 605-647). Amsterdam: Elsevier Science Publisher.

Christoph, N., Leemkuil, H., Ootes, S., Shostak, I., & Monceaux, A. (2003). *Final evaluation report on the use of the final kits learning environment prototype* (No. D14). Enschede: KITS Consortium (Project number IST-1999-13078).

Christoph, N., Van der Tang, F., & De Hoog, R. (2001). *Intuitive knowledge management strategies.* Paper presented at the 2nd European Conference on Knowledge Management (ECKM), Bled, Slovenia.

Cleveland, W. S. (1994). *The elements of graphing data*. Hampshire: Chapman & Hall.

Coll, R. A., Coll, J. H., & Thakur, G. (1994). Graphs and tables: A four-factor experiment. *Communication of the ACM, 37*(4), 77-86.

Corbeil, P. (1999). Learning from children: Practical and theoretical reflections on playing and learning. *Simulation & Gaming, 30*(2), 163-180.

Daft, R. L., Lengel, R. H., & Trevino, L. K. (1987). Message equivocality, media selection, and manager performance: Implications for information system. *MIS Quarterly, 11*(3), 355-366.

Daft, R. L., & Wiginton, J. C. (1979). Language and organization. *Academy of Management Review, 49*(2), 179-191.

De Hoog, R., Shostak, I., Purbojo, R., Anjewierden, A., Christoph, N., & Kruizinga, E. (2002). *Final models and visualization* (D12). Enschede: KITS Consortium (Project number IST-1999-13078).

De Hoog, R., Van Heijst, G., Van Der Spek, R., Edwards, J. S., Mallis, R., Van Der Meij, B., et al. (1999). Investigating a theoretical framework for knowledge management: A gaming approach. In J. Liebowitz (Ed.), *Knowledge management handbook*. Boca Raton: CRC Press LLC.

Dennis, A. R., & Kinney, S. T. (1998). Testing media richness theory in the new media: The effects of cues, feedback, and task equivocality. *Information Systems Research, 9*(3), 256-274.

DeSanctis, G. (1984). Computer graphics as decision aids: Directions for research. *Decision Sciences, 15*, 463-487.

Dickson, G. W., DeSanctis, G., & McBride, D. J. (1986). Understanding the effectiveness of computer graphics for decision support: A cumulative experimental approach. *Communication of the ACM, 29*(1), 40-47.

Dijkstra, J., & Verwijs, C. (2000). *Improving the learning ability of groups in the organisation.* Paper presented at the KMAC2000, Birmingham.

Druckman, D. (1995). The education effectiveness of interactive games. In D. Crookall & K. Arai (Eds.), *Simulation and gaming across disciplines and cultures: ISAGA at a watershed* (pp. 178-187). Thousand Oaks, CA: Sage.

Ehrenberg, A. S. C. (1977). Rudiments of numeracy. *Journal of the Royal Statistical Society. Series A (General), 140*(3), 277-297.

Ehrenberg, A. S. C. (1978). Graphs or tables. *Statistician, 27*(2), 87-96.

Ehrenberg, A. S. C. (1981). The problem of numeracy. *The American Statiscian, 35*(2), 67-71.

Eklundh, K. S., Groth, K., Hedman, A., Lantz, A., Rodriguez, H., & Sallnas, E.-L. (2003). The world wide web as a social infrastructure for knowledge-oriented work. In H. v. Oostendorp (Ed.), *Cognition in a digital world*. New Jersey: Lawrence Erlbaum Associates, Inc.

Ellington, H., & Early, S. (1998). *Using games, simulations, and interactive case studies: A practical guide for tertiary-level teachers*. Aberdeen: Centre for Learning and Assessment The Robert Gordon University.

Erev, I., & Cohen, B. L. (1990). Verbal versus numerical probabilities: Efficiency, bias, and the preference paradox. *Organizational behavior and human decision processes, 45*(1).

Farnham, S., Chesley, H. R., McGhee, D. E., Kawal, R., & Landau, J. (2000). *Structured online interaction: Improving the decision-making of small discussion groups.* Paper presented at the CSCW'00, Philadelphia.

Fisher, B. A. (1974). *Small group decision making: Communication and the group process*. New York: McGraw-Hill, Inc.

Freedman, E. G., & Shah, P. (2002). Toward a model of knowledge-based graph comprehension. In M. Hegarty, B. Meyer & N. H. Narayanan (Eds.), *Diagrams 2002* (pp. 249-263). Berlin Heidelberg: Springer-Verlag.

Fussell, S. R., Kraut, R. E., & Siegel, J. (2000). *Coordination of communication: Effects of shared visual context on collaborative work.* Paper presented at the CSCW2000: Conference on Computer Supported Cooperative Work.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation & Gaming, 33*(4).

Gigerenzer, G. (2000). *Adaptive thinking: Rationality in the real world*. Oxford: Oxford University Press.

Gray, M., Hodson, N., & Gordon, G. (1994). *Teleworking explained*. Chichester: John Wiley & Sons Ltd.

Gredler, M. E. (1996). Educational games and simulations: A technology in search of a (research) paradigm. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology*. New York: Macmillan Library Reference, USA.

Grice, H. P. (1975). Logic and conversation. In P. Cole & J. L. Morgan (Eds.), *Syntax and semantic: Speech act* (Vol. 3, pp. 41-43). San Francisco: Academic Press.

Guirdham, M. (1996). *Interpersonal skills at work*. London: Prentice Hall Europe.

Gundry, J., & Metes, G. (1996). Team knowledge management: A computer-mediated approach. *A white paper from Knowledge Ability Ltd and Virtual learning systems, Inc.*, from www.knowaab.co.uk/wbwteam

Gutwin, C., & Greenberg, S. (1999). The effects of workspace awareness support on the usability of real-time distributed groupware. *ACM transactions on Computer Human Interaction, 6*(3), 243-281.

Harvey, N., & Bolger, F. (1996). Graphs versus tables: Effects of data presentation format on judgmental forecasting. *International Journal of Forecasting, 12*, 119-137.

Healey, C. G. (1996). Choosing effective colours for data visualization. In R. Yagel & G. M. Nielson (Eds.), *Proceedings Visualization '96* (pp. 263-270). IEEE Computer Society.

Hirokawa, Y. R., & Poole, S. M. (1996). *Communication and group decision making* (2nd ed.). London: Sage Publications.

Hitchcock, D. E., & Willard, M. L. (1995). *Why teams can fail and what to do about it*. Chicago: Irwin Professional Publishing.

Huang, W. W. (2003). Impacts of GSS generic structures and task types on group communication process and outcome: Some expected and unexpected research findings. *Behaviour & Information Technology, 22*(1), 17-29.

Huysman, M., Steinfield, C., Jang, C.-Y., David, K., Veld, M. H. i. t., Poot, J., et al. (2003). Virtual teams and the appropriateness of communication technology: Exploring the concept of media stickiness. *Computer Supported Cooperative work, 12*, 411-436.

Isaacs, W., & Senge, P. (1992). Overcoming limits to learning in computer-based learning environments. *European Journal of Operational Research, 59*, 183-196.

Jacobs, J. W., & Dempsey, J. V. (1993). Simulation and gaming: Fidelity, feedback and motivation. In J. V. Dempsey & G. C. Sales (Eds.), *Interactive instruction and feedback*. Englewood Cliffs, New Jersey: Educational Technology Publications.

Johnson, D. W., & Johnson, F. P. (2000). *Joining together: Group theory and group skills* (7th ed.). Boston: Allyn & Bacon.

Johnson, D. W., & Johnson, R. T. (1990). Cooperative learning and achievement. In S. Sharan (Ed.), *Cooperative learning: Theory and research* (pp. 23-37). New York: Praeger.

Jones, Q. (1997). Virtual-communities, virtual-settlements & cyber-archaeology: A theoretical outline. *Journal of Computer-Mediated Communication*, from http://www.ascusc.org/jcmc/vol3/issue3/jones.html

Joshi, K. D. (2001). A framework to study knowledge management behaviours during decision making. In R. H. S. Jr (Ed.), *Proceedings of the 34th Hawaii International Conference on System Science 2001*. Los Alamitos: The Institute of Electrical and Electronics Engineers Computer Society.

Junnarkar, B. (1997). Leveraging collective intellect by building organisational capabilities. *Expert System with Application, 13*(1), 29-40.

Kepner, C. H., & Tregoe, B. B. (1981). *The new rational manager*. Princeton: Princeton Research Press.

Kjeldskov, J., & Stage, J. (2003). *A mobile device for text-based communication in a safety-critical domain*. Paper presented at the Interact 2004.

Klabbers, J. (1999). Three easy pieces: A taxonomy on gaming. In D. Sounders & J. Severn (Eds.), *Simulation and gaming year book vol. 7. Simulation and games for strategy and policy planning*. London: Kogan Page.

Knauff, M., & Johnson-Laird, P. N. (2002). Visual imagery can impede reasoning. *Memory & Cognition, 30*(3), 363-371.

Kossyln, S. M. (1994). *Elements of graph design*. New York: Freeman.

Kramer, A., & Spinks, J. (1991). Capacity views of human information processing. In J. R. Jennings & M. G. H. Coles (Eds.), *Handbook of cognitive psychophysiology: Central and autonomic nervous system approaches*. London: John Wiley & Sons.

Krasavvidis, I. (1999). *Learning to solve correlation problems: A study of the social and material distribution of cognition.* University of Twente, Enschede.

Kraut, R. E., Gergle, D., & Fussell, S. R. (2002). The use of visual information in shared visual spaces: Informing the development of virtual co-presence. In *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work*. New York: ACM Press.

Kriz, W. C. (2003). Creating effective learning environments and learning organizations through gaming simulation design. *Simulation & Gaming, 34*(4), 495-511.

Kunkel, J. G., & Shafer, W. E. (1997). Effects of student team learning in undergraduate auditing course. *Journal of Education for Business, 72*, 197-200.

Larichev, O. I., & Brown, R. V. (2000). Numerical and verbal decision analysis: Comparison on practical cases. *Journal of Multi-Criteria Decision Analysis, 9*, 263-273.

Leemkuil, H., Christoph, N., De Hoog, R., De Jong, T., Ootes, S., Purbojo, R., et al. (2002). *Final specification of the instructional envelop*. Enschede: KITS Consortium (Project number IST-1999-13078).

Leemkuil, H., De Jong, T., De Hoog, R., & Christoph, N. (2003). KM Quest: A collaborative internet-based simulation game. *Simulation & Gaming, 34*(1), 89-111.

Leemkuil, H., De Jong, T., Ootes, S., Shostak, I., Purbojo, R., De Hoog, R., et al. (2001). *Initial specification of the instructional envelope* (D5). Enschede: KITS Consortium (Project number IST-1999-13078).

Legrenzi, P., Girotto, V., & Johnson-Laird, P. N. (1993). Focusing in reasoning and decision making. In P. N. Johnson-Laird & E. Shafir (Eds.), *Reasoning and decision making*. Cambridge: Blackwell.

Leigh, E., & Spindler, L. (2004). Simulation and games as chaordic learning contexts. *Simulation & Gaming, 35*(1), 53-69.

Leshin, C. B., Pollock, J., & Reigeluth, C. M. (1992). *Instructional design strategies and tactics*. New Jersey: Educational Technology Publications, Inc.

Lichtenstein, S., Slovic, P., Fischhoff, B., Layman, M., & Combs, B. (1978). Judged frequency of lethal events. *Journal of Experimental Psychology: Human Learning and Memory, 4*, 551-578.

Machuca, J. A. D. (2000). Transparent-box business simulators: An aid to manage the complexity of organizations. *Simulation & Gaming, 31*(2), 230-239.

Mackenzie-Taylor, M. (1999). Developing design through dialogue: Transport tables and graphs. In H. J. G. Zwaga., T. Boersema. & H. C. M. Hoonhout. (Eds.), *Visual information for everyday use: Design and research perspectives*. London: Taylor and Francis.

Mahon, B. H. (1977). Statistic and decisions: The importance of communication and the power of graphical presentation. *Journal of the Royal Statistical Society. Series A (General), 140*(3), 298-323.

Marakas, G. M. (1999). *Decision support system in 21st century*. New Jersey: Prentice-Hall, Inc.

Marquardt, M. J. (1999). *Action learning in action*. Palo Alto: Davies-Black Publishing.

McGuire, T. W., Kiesler, S., & Siegel, J. (1987). Group and computer-mediated discussion effects in risk decision making. *Journal of Personality and Social Psychology, 52*(5), 917-930.

McKenzie, D. L., & Padilla, M. J. (1986). The construction and validation of the test of graphing in science. *Journal of Research in Science Teaching, 23*(7), 571-579.

Meyer, J. (2000). Performance with tables and graphs: Effects of training and a visual search model. *Ergonomics, 43*(11), 1840-1865.

Nelson, L. M. (1999). Collaborative problem solving. *Instructional Design Theory and Model: A new paradigm of Instructional Theory, 2*, 241-267.

Neuendorf, K. A., & Skalski, P. D. (2002). *The content analysis guidebook.* Thousand Oaks: Sage.

Nicolas, R. (2004). Knowledge management impacts on decision making process. *The Journal of Knowledge Management, 8*(1), 20-31.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. New York: Oxford University Press.

Palmer, J. W., & Speier, C. (1998). Teams: Virtualness and media choice. *International Journal of Electronic Commerce, 3*(1), 27-48.

Person, N. K., & Graesser, A. G. (1999). Evolution of discourse during cross-age tutoring. In A. M. O'Donnel & A. King (Eds.), *Cognitive perspective on peer learning*. London: Lawrence Erlbaum Associates.

Pierfy, D. A. (1977). Comparative simulation game research. *Simulation & Games, 8*, 255-268.

Poole, M. S. (1978). An information-task approach to organizational communication. *Academy of Management Review, 30*, 493-504.

Preece, J. (2001). Sociability and usability in online communities: Determining and measuring success. *Behaviour & Information Technology, 20*(5), 347-356.

Propp, K. M. (1999). Collective information processing in groups. In L. R. Frey (Ed.), *The handbook of group communication theory and research*. Thousand Oaks: Sage Publications.

Purbojo, R., & De Hoog, R. (2004). Learning knowledge management in a collaborative game: Effects of player preparation and visualization of variables. In W. C. Kriz & T. Eberle (Eds.), *Bridging the gap: Transforming knowledge into action through gaming and simulation*. Munich: Swiss Austrian German Simulation and Gaming Association (SAGSAGA).

Rangecroft, M. (2003). As easy as pie. *Behaviour & Information Technology, 22*(6), 421-426.

Rao, R., & Sprague, R. H. (1998). Natural technologies for knowledge work: Information visualisation and knowledge extraction. *Journal of Knowledge Management, 2*(2), 70-80.

Reiss, N. (1985). *Speech act taxonomy as a tool for ethnographic descriptions: An analysis based on videotapes of continous behaviour in two New York households.* Amsterdam: John Benjamin Publishing Company.

Roth, W. M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching, 36*(9), 977-1019.

Rutter, D. R., & Robinson, B. (1981). An experimental analysis of teaching by telephone: Theoretical and practical implications for social psychology. In G. M. Stephenson & J. H. Davis (Eds.), *Progress in applied social psychology*. John Wiley & Sons, Ltd.

Schrage, M. (1990). *Shared minds*. New York: Random House, Inc.

Scott, C. R. (1999). Communication technology and group communication. In L. R. Frey (Ed.), *The handbook of group communication theory & research*. Thousand Oaks: Sage Publications.

Senge, P. M. (1990). *The fifth discipline. The art of practice of the learning organization.* New York: Currency Doubleday.

Senn, J. A. (1995). *Information technology in business* (2nd ed.). New Jersey: Prentice Hall.

Shah, P., & Carpenter, P. A. (1995). Conceptual limitations in comprehending line graphs. *Journal of Experimental Psychology: General, 124*(1), 43-61.

Shah, P., Mayer, R. E., & Hegarty, M. (1999). Graph as aids to knowledge construction: Signaling techniques for guiding the process of graph comprehension. *Journal of Educational Psychology, 91*(4), 690-702.

Shneiderman, B. (1992). Tree visualization with tree-maps: 2-d space-filling approach. *ACM transactions on Graphics, 11*(1), 92-99.

Simon, H. A. (1977). *The new science of management decision*. Englewood Cliffs: Prentice-Hall.

Smith, P. L., & Ragan, T. J. (1999). *Instructional design* (2nd ed.). New Jersey: Prentice-Hall, Inc.

Sproull, L., & Kiesler, S. (1991). *Connections: New ways of working in the networked organization*. Massachusetts: The MIT Press.

Stahl, G., Herrmann, T., & Carell, A. (2004). Kommunikationskonzepte. *CSCL-Kompendium*, from http://www.cis.drexel.edu/faculty/gerry/cscl/papers/papers.html

Stahl, I. (1983). *Operational gaming: An international approach*. Oxford, England: Pergamon Press.

Stevens, S. S. (1946). On the theory of scales of measurement. *Science, 103*, 667-680.

Sveiby, K.-E. (2001). What is knowledge management?, from http://www.sveiby.com/articles/KnowledgeManagement.html#KMInitatives

Sveiby, K.-E. (2002). Collaborative climate and effectiveness of knowledge work - an empirical study. *Journal of Knowledge Management, 6*(5), 420-433.

Tabatabaei, M. (2002). An experimental analysis of decision channeling by restrictive information display. *Journal of Behaviour Decision Making, 15*, 419-432.

Tegarden, D. P. (1999). Business information visualization. *Communication of the Association for Information Systems, 1*(4), 1-38.

Thomsen, E. (2000). Data vs. Knowledge. *Decision Support, 3*(6).

Trafton, J. G., & Trickett, S. B. (2002). A new model of graph and visualization usage. In M. Hegarty, B. Meyer & N. H. Narayanan (Eds.), *Diagrams 2002*. Berlin, Heidelberg: Springer-Verlag.

Treacy, M., & Wiersema, F. (1995). *The discipline of market leaders*. New York: Harvard Business Press.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124-1131.

Van Heijst, G., van der Spek, R., & Kruizinga, E. (1997). Corporate memories as a tool for knowledge management. *Expert System with Application, 13*(1), 41-54.

Van Merriënboer, J. J. G. (1997). *Training complex cognitive skills: A four-component instructional design model for technical training.* Engelwood Cliffs, NJ: Educational Technology Publications.

Veermans, K. (2003). *Intelligent support for discovery learning.* Enschede: Twente University Press.

Vessey, I., & Galletta, D. (1991). Cognitive fit: An empirical study of information acquisition. *Information Systems Research 2.1*, 63-84.

Ware, C. (2000). *Information visualization: Perception for design.* San Francisco: Morgan Kaufmann Publisher.

Watkins, K. E., & Marsick, V. J. (1993). *Sculpting the learning organization: Lessons in the art of science of systemic change.* San Francisco: Jossey-Bass Inc.

Wenzler, I., & Chartier, D. (1999). Why do we bother with games and simulations: An organizational learning perspective. *Simulation & Gaming, 30*(3), 375-384.

Wielinga, B., Sandberg, J., & Schreiber, G. (1997). Methods and techniques for knowledge management: What has knowledge engineering to offer? *Expert System with Application, 13*(1), 73-84.

Wiig, K. M. (1995). *Knowledge management methods: Practical approach to managing knowledge*. Arlington, Texas: Schema Press.

Wiig, K. M. (1997). Knowledge management: Where did it come from and where will it go? *Expert Systems With Applications, 13*(1), 1-14.

Wiig, K. M., De Hoog, R., & Van der Spek, R. (1997). Supporting knowledge management: A selection of methods and techniques. *Expert System with Application, 13*(1), 15-27.

Wileman, R. E. (1993). *Visual communication.* New Jersey: Educational Technology Publications.

Williams, E. (1977). Experimental comparison of face-to-face and mediated communication: A review. *Psychological Bulletin, 84*(5), 963-976.

Winslow, C. D., & Bramer, W. L. (1994). *Futurework: Putting knowledge to work in the knowledge economy.* New York: The Free Press.

Appendix A:

Summary of visualisation of the business model

Nr.	Package's Name	Code	Name of Variables (Main Display)	Sub display	Type of chart	Domain
1			***Organisational Effectiveness variables***			
1.1	Market share	MS	Market share		Combination chart : Pie, Stacked Vertical Bar, & Line	none
		OS		Other market share		
1.2	Customer Satisfaction	CSI	Customer satisfaction index		Combination: Vertical Bar & Iconic (Billboard)	none
1.3	Profit	Profit	Profit		Combination chart: Vertical Bar & Line	none
1.7	Turnover	Turnover	Turnover		Vertical Bar	all
1.8	Expenses	NOE	Non-operating expenses		Combination chart: Clustered bar & Numerical	all
		TOE	Total operating expenses			all
		Exso		Other expenses		all
		Exsr		R&D expenses		all
		Exst		Training expenses		all
1.9	Employees	Emp	Total number of employees		Stacked Bar	all
		EmpM		Number of Marketing Employees		
		EmpR		Number of R&D Employees		
		EmpO		Number of Other Employees		
1.10	Job Satisfaction	JSI	Average job satisfaction index of employees		Combination: Vertical Bar and Symbols (Smiley)	all
1.11	Level of Sales	SalesL	Level of sales		Vertical Bar	none

2			***Business Process related variables***			
2.1	Time of New Products to Market	ATM	Average time for new product to market		Horizontal Bar	marketing
2.2	Employees of Marketing	EmpM	Number of marketing employees		Vertical Bar	marketing
2.3	Level of Sales based on Marketing	SalesL_M	Level of sales based on marketing		Vertical Bar	marketing
2.4	Time of changing New Products	ATP	Average time to change for producing a new product		Horizontal Bar	production
2.5	Number of Other Employees	EmpO	Number of other employees		Vertical Bar	production
2.6	Production Level	ProdL	Production level		Combination chart: Vertical Bar & Line	production
2.7	Employees in R&D	EmpR	Number of research employees		Vertical Bar	research
2.8	Potential Market Share	MS_pot	Potential market share		Combination chart: Pie, Vertical Stacked Bar, & Line	research
		OS_pot		Potential other's market share		
2.9	Product Quality	PQI	Company product quality index		Line	research
2.10	Patents	Pat	Total number of company patents		Combination chart: Clustered & Vertical Bar	research
		Pat_new		New patents		research
		Pat_pen		Patents pending		research
2.11	Number of Production	Prod	Number of products		Line	research
2.12	Products	Prod_dev	Products in development		Clustered Vertical Bar	research
		Prod_new		New products		research
2.13	Level of Sales based on Product Quality	SalesL_PQI	Level of sales based on the product quality		Vertical Bar	research
3			***Knowledge Related Variables***			
3.1	Competence in Production	CP	Average level of competence in production		line	production
3.2	Competence in R&D	CR	Average level of competence in R&D		line	research

3.2	Competence in Marketing	CM	Average level of competence in marketing		line	marketing
4			***Knowledge Processes Variables***			
4.1	Effectiveness Of Knowledge Processes in Marketing	KDeM	Effectiveness of knowledge development in marketing		Line	marketing
		KGeM		Effectiveness of knowledge gaining in marketing		marketing
		KReM		Effectiveness of knowledge retention in marketing		marketing
		KTeM		Effectiveness of knowledge transfer in marketing		marketing
		KUeM		Effectiveness of knowledge utilisation in marketing		marketing
4.2	Efficiency of Knowledge Processes in Marketing	KDefM	Efficiency of knowledge development in marketing		Line	marketing
		KGefM		Efficiency of knowledge gaining in marketing		marketing
		KTefM		Efficiency of knowledge transfer in marketing		marketing
		KUefM		Efficiency of knowledge utilisation in marketing		marketing
4.3	Speed of Knowledge Processes in Marketing	KDsM	Speed of knowledge development in marketing		Line	marketing
		KGsM		Speed of knowledge gaining in marketing		marketing
		KTsM		Speed of knowledge transfer in marketing		marketing
		KUsM		Speed of knowledge utilisation in marketing		marketing

4.4	Effectiveness of Knowledge Processes in Production	KDeP	Effectiveness of knowledge development in production		Line	production
		KGeP		Effectiveness of knowledge gaining in production		production
		KReP		Effectiveness of knowledge retention in production		production
		KTeP		Effectiveness of knowledge transfer in production		production
		KUeP		Effectiveness of knowledge utilisation in production		production
4.5	Efficiency of Knowledge Processes in Production	KDefP	Efficiency of knowledge development in production		Line	production
		KGefP		Efficiency of knowledge gaining in production		production
		KTefP		Efficiency of knowledge transfer in production		production
		KUefP		Efficiency of knowledge utilisation in production		production
4.6	Speed of Knowledge Processes in Production	KDsP	Speed of knowledge development in production		Line	production
		KGsP		Speed of knowledge gaining in production		production
		KTsP		Speed of knowledge transfer in production		production
		KUsP		Speed of knowledge utilisation in production		production
4.7	Effectiveness of Knowledge Processes in Research	KDeR	Effectiveness of knowledge development in research		Line	research
		KReR		Effectiveness of knowledge retention in research		research

		KTeR		Effectiveness of knowledge transfer in research		research
		KUeR		Effectiveness of knowledge utilisation in research		research
		KGeR		Effectiveness of knowledge gaining in research		research
4.8	Efficiency of Knowledge Processes in Research	KDefR	Efficiency of knowledge development in research		Line	research
		KGefR		Efficiency of knowledge gaining in research		research
		KTefR		Efficiency of knowledge transfer in research		research
		KUefR		Efficiency of knowledge utilisation in research		research
4.9	Speed of Knowledge Processes in Research	KDsR	Speed of knowledge development in research	Speed of knowledge development in research	Line	research
		KGsR		Speed of knowledge gaining in research		research
		KTsR		Speed of knowledge transfer in research		research
		KUsR		Speed of knowledge utilisation in research		research
	Total=	33 Packages				

Appendix B:

Preview of the case study: Coltec Company

History

Coltec is a manufacturer of adhesives, coatings, headquartered in Utrecht, The Netherlands. Coltec was established in 1968. Initially, Coltec operated in the market of custom formulated adhesives and coatings. During this period the company developed a unique competence in the development and manufacturing of coatings and adhesives for extreme temperatures. Based on this competence, Coltec developed in the seventies a series of standardised products for the industrial market. In 1981 Coltec was acquired by the Namco Group, a leading USA-based consortium in the chemical industry. In the eighties, Coltec extended its activities to include consumer products (do it yourself glues etc.). Within the Namco Group Coltec operates as an independent company. It develops, manufactures and sells its own products. Since the acquisition by Namco, Coltec has steadily extended its range of products. Two years ago, Coltec offerer various products, ranging from high performance adhesives used in space-engineering to D.I.Y. products. Coltec currently operates in 23 countries in Europe and the Middle East. It has production plants in 12 European countries, and it employed 5000 people.

Product

Coltec produces about 250 products, divided over 7 product divisions. The product divisions are: Custom made construction adhesives, High performance adhesives, Waterproof membranes, Tiling adhesives and additives, Vinyl adhesives, Coatings, and Abrasives.

Organisation

In Coltec there are three main functions: marketing and sales, research and development and manufacturing. Further, there are four staff functions: human research management, strategic planning, finance and information technology. Figure 1 shows the organisation chart of Coltec.

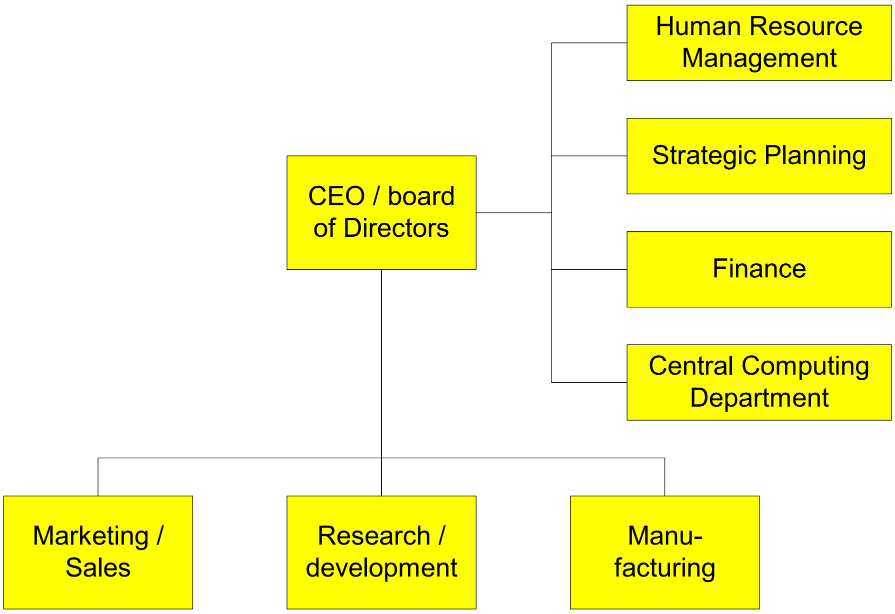


Figure 1: Organisation chart of Coltec

Marketing and sales

Marketing and Sales is organised on a country/regional basis. Within each country it is subdivided following the 7 main product divisions. There are marketing and sales organisations in 23 countries in Europe and the Middle East. In total approx. 300 people work in marketing and sales. At the head office there is a small department (10 people) which co-ordinates the marketing efforts in the different countries.

Research and development

Research and Development is located in Delft, the Netherlands. Coltec spends about 20% of its turnover on research and development. In total about 200 people work in Research and Development.

Manufacturing/Production

The manufacturing department is divided in 7 product divisions. Most of the product divisions have plants in multiple countries:

- High performance adhesives one plant in Sweden, one plant in Spain and one plant in Austria.
- Waterproof membranes one plant in Ireland.
- Tiling adhesives and additives one plant in Portugal and one plant in Poland
- Vinyl adhesives two plants in France (one in Lille, one in Clermont Ferrand).
- coatings one plant in the Netherlands, one in England and one in Italy.
- Custom made construction adhesives one plant in the Netherlands.
- Abrasives one plant in Belgium, one plant in Germany.

Supporting staff for CEO

Coltec's CEO and the board of directors are supported by a staff of about 100 people, organised in four groups:

- *Human Resource Management*; The goal of this staff function is to develop company wide strategic directions for the acquisition, deployment and use of human resources in Coltec. This groups measures every two years the average job satisfaction of Coltec's employee's.
- *Strategic Planning;* This staff function investigates future opportunities and markets for Coltec, and develops business strategies.
- *Finance* develops and enforces company wide accounting standards and reports quarterly to the board
- *Central computing department;* The role of the central computing department is to keep track of the various computer systems that are being used in Coltec. At this moment, Coltec mainly uses mainframe computer systems with character based terminals. The Research and Development department uses a PC network.

Market

Coltec operates in a high-tech, steadily growing market. The market is characterised by short product life cycles. Coltec has an average market share of about 27% of the European market, but almost no market share elsewhere. There are few new entrants in the market, but the number of competitors is growing, mainly because more and more American adhesives manufacturers are beginning to operate in Europe. Coltec is planning to extend its activities to other parts of the world, but has not yet decided on a strategy to do so.

Mission

In terms of the value discipline theory of Treacy and Wiersema, Coltec should be positioned as a typical product leader. Coltec tries to beat its competitors by delivering better, higher quality, products or services. This puts a strong emphasis on the role of the Research and Development department. Although this emphasis on product leadership is most visible in the consumer market, where Coltec products typically are positioned at the high end, it is also true for the business-to-business market, where the buyers mostly use Coltec products for high-end products.

Appendix C:

List of KM interventions

Nr.	Interventions
I1	Hire a high-class expert with new marketing knowledge temporary
I2	Hire a high class expert with new research knowledge temporary
I3	Hire a high class expert with new marketing knowledge permanently
I4	Hire a high class expert with new research knowledge permanently
I5	Hire people in marketing on the permanent base
I6	Hire people in the research area on the permanent base
I7	Hire people in the production on the permanent base
I8	Hire an external project team to develop a new product
I9	Contract marketing agencies to conduct a market research to learn customers' priorities and competitors' advances in products and services
I10	Contract marketing agencies on a regular basis once a year to learn customers' priorities and competitors' advances in products and services
I11	Make a joint recruiting programme (including sponsorships and bonuses) with universities and high schools to recruit high-scores graduated students with marketing knowledge
I12	Make a joint recruiting programme with universities, high schools, and colleges to recruit high-scores graduated students with research knowledge research
I13	Make a joint recruiting programme with schools for professional education to recruit staff with production knowledge
I14	Subscribe to professional newsletters and magazines in the marketing area
I15	Subscribe to professional newsletters and magazines in the research area
I16	Regularly send your researchers to the professional conferences
I17	Install Internet connection
I18	Install connection to external non-public computer networks and data bases to get professional information
I19	Conduct in-house training programme in marketing and sales
I20	Conduct in-house training programme in research
I21	Conduct in-house training programme in production
I22	Conduct external training programme in marketing and sales
I23	Conduct external training programme in research
I24	Conduct on-the-job training in marketing and sales
I25	Conduct on-the-job training in research
I26	Conduct on-the-job training in production
I27	Conduct IT literacy training programme
I28	Organise apprenticeship system
I29	Conduct training programme to develop research skills
I30	Organise information-sharing sessions for research employees on the regular basis
I31	Organise information-sharing sessions for marketing employees on the regular basis
I32	Co-operate with partners to design a new product
I33	Co-operate with partners to produce a product
I34	Co-operate with the partner to address new markets and customer groups
I35	Produce and distribute manuals with processes and work flow related job descriptions including job & safety protocols
I36	Implement an employee suggestions and initiatives reward system
I37	Implement job rotation and job enrichment system

I38	Create databases with information about current and past research projects
I39	Create databases with marketing information
I40	Create a cross-departmental work group from employees of marketing and sales, research, and production and request them to have a monthly meetings to exchange information
I41	Organise monthly meetings between production and research employees to exchange information
I42	Organise monthly meetings between marketing and research employees to exchange information
I43	Organise monthly meetings between marketing and production employees to exchange information
I44	Implement a company information system which supports Intranet and forums to conduct E-discussions and make available news about ongoing research projects and product developments
I45	Implement a bonus system for employees to keep them in the organisation
I46	Implement a reward/bonus system for participation in the knowledge distribution processes for employees
I47	Conduct a training programme that aims at improving employees' motivation and attitude
I48	Conduct a training programme that aims at team-building
I49	Implement a bonus system for employees effectiveness
I50	Conduct external training programme in production
I51	Conduct a new research project for external agencies
I52	Conduct a marketing campaign to introduce new products features
I53	Implement a "safety and ergonomic environment" system
I54	Change organisational policy towards self-managing teams
I55	Implement a back-up system
I56	Conduct a training program in order to meet standardisation and TQM (Total quality management) requirements

9 Nederlandse samenvatting

In organisaties waar beslissingsgericht werken steeds belangrijker wordt neemt de rol van kennis navenant toe. Immers bij het nemen van beslissingen is de belangrijkste hulpbron niet van fysieke aard, zoals bijvoorbeeld wel het geval is bij het maken van tastbare producten. Kennis als hulpbron heeft een aantal eigenschappen waardoor het afwijkt van andere hulpbronnen die kunnen worden ingezet. Een van de belangrijkste is dat het in hoge mate tijd- en plaatsonafhankelijk kan worden gebruikt, eventueel zelfs in parallel. Het gevolg hiervan is dat organisatorische processen die hoofdzakelijk van kennis gebruik maken ook veel minder gebonden zijn aan een specifieke tijd en plaats, hetgeen leidt tot een toenemende geografische verspreiding van kennis en kennisdragers. Daartegenover staat de tendens dat beslissingsgericht werken steeds meer een gezamenlijke activiteit wordt. De meeste beslissingen zijn zodanig complex dat slechts het samenbrengen van verschillende kennisbronnen tot succesvolle uitkomsten kan leiden. De vraag is hoe deze tegenwerkende ontwikkelingen met elkaar in harmonie kunnen worden gebracht. Het ligt voor de hand om daarbij vooral te kijken naar de mogelijkheden die informatie- en communicatietechnologie (ICT) te bieden heeft. Door de opkomst van Internet is het overbruggen van barrières van tijd en plaats aanzienlijk eenvoudiger geworden, zowel via complexe (bijvoorbeeld Videoconferencing) als betrekkelijk eenvoudige (chat) middelen. De vraag die daarbij rijst is of ICT daadwerkelijk een bijdrage kan leveren aan het effectief samenbrengen van kennis, vooral wanneer sprake is van een beperkte brandbreedte in de communicatie. Chat via Internet is aantrekkelijk omdat de kosten laag zijn in verhouding met andere mogelijkheden, zelfs wanneer communicatie met ondersteuning van Webcams plaatsvindt. Deze dissertatie richt zich dan ook op de vraag of via goed ontworpen visuele hulpmiddelen de communicatieprocessen tussen geografisch verspreide beslissers in een kennisintensieve context, gebruik makend van een beperkte bandbreedte, verbeterd kunnen worden, met als gevolg een beter beslisproces en een grotere tevredenheid bij de deelnemers met dit beslisproces. Onderzoek naar deze vraag kan op verschillende manieren ingericht worden, hier is gekozen voor een experimentele laboratorium aanpak, dit in tegenstelling tot een aantal gevalsstudies in het veld. De belangrijkste reden voor deze keuze is de lastige toegankelijkheid van organisaties voor empirisch onderzoek op dit gebied enerzijds en anderzijds de geringe mogelijkheid om in zo'n veldcontext relevante factoren onder controle te houden.

Als domein voor het onderzoek is gekozen voor het gezamenlijk leren van kennismanagement via een computersimulatie. Aan deze keuze liggen twee overwegingen ten grondslag:

1. Kennismanagement als inhoudelijke theorie kan een bijdrage leveren aan het structureren van kennisintensieve beslissingsprocessen en biedt zo een mogelijke oplossing voor problemen op dit terrein.
2. Het gezamenlijk leren van kennismanagement in een simulatiecontext is zelf een kennisintensieve taak die gelijkenis vertoont met de manier waarop in

organisaties beslissingen worden genomen, waardoor het realiteitsgehalte van de leercontext toeneemt.

Daarnaast is door middel van het simuleren van geografische spreiding en het beperken van de communicatie tot chat en on-line toegang tot informatie over de organisatie, een situatie gecreëerd die, voorzover mogelijk in een laboratoriumsituatie, de werkelijkheid benadert.

Teneinde de eerste overweging hierboven te kunnen realiseren moet er een model of theorie voor kennismanagement zijn die kan dienen als structurering van kennismanagement processen. In de literatuur zijn een groot aantal van dergelijke modellen voorhanden. In de context van deze dissertatie is gekozen voor een model dat een duidelijke conceptuele en procedurele scheiding aanbrengt tussen management en het te managen proces. De gebruikte theorie maakt dit onderscheid concreet door een apart procedureel model voor het inrichten van het management proces en een apart descriptief simuleerbaar model van de bedrijfsprocessen waarop kennismanagement geacht wordt in te grijpen. Beide modellen zijn aan elkaar gekoppeld door enerzijds de interventies die managers kunnen uitvoeren in de organisatie en anderzijds door informatie over de effecten van deze interventies op de organisatie. Daardoor ontstaat er een cyclus waarbij interventies en effecten elkaar afwisselen en het voor de hand ligt dat bij het beslissen over een volgende verzameling interventies informatie over de toestand van de organisatie een belangrijke rol speelt. De kernvraag is dan hoe bij een beperkte bandbreedte, geografisch verspreide beslissers toch in staat zijn deze informatie te interpreteren en te gebruiken. Wat betreft de tweede overweging geldt dat in de literatuur veel aanwijzingen zijn over positieve bijdrage die gezamenlijk leren via simulaties kan hebben. Dit heeft te maken met zowel het realiteitsgehalte, maar ook met indicaties dat gezamenlijk leren vaak effectiever is dan individueel leren.

Combinatie van beide overweging leidt tot een onderzoekscontext waarin individuen gezamenlijk leren door het nemen van beslissingen die effect hebben op een organisatie. Leren en beslissen zitten dus in elkaar verweven. Op basis van de literatuur is een globaal model van het beslisproces geformuleerd, bestaande uit drie fasen, waarmee het probleemoplosgedrag van de lerenden kan worden geanalyseerd en vragen met betrekking tot de effectiviteit van dit proces kunnen worden beantwoord. In dit proces nemen communicatieprocessen tussen de beslissers een centrale plaats in. Wanneer deze communicatieprocessen niet goed verlopen kan verwacht worden dat als gevolg daarvan zowel het beslisproces als de uitkomsten ervan minder positief zijn en als zodanig worden ervaren door de beslissers. Hierbij speelt, zoals al eerder gezegd, bandbreedte van het communicatiekanaal een belangrijke rol. Op basis van de Media Richness Theory valt te voorspellen dat in een context met relatief grote onzekerheid over de taak en het gebrek aan informatie die daarvoor nodig is en onduidelijkheid over de interpretatie van die informatie, communicatiekanalen met een beperkte bandbreedte minder geschikt zullen zijn. Dit ziet echter de mogelijkheid over het hoofd om door middel van goed doordachte representatie van deze informatie de belemmering die voortkomen uit de bandbreedte te compenseren. Ook uit ander onderzoek, onder andere in de cognitieve psychologie, komt naar voren dat een goede representatie van informatie kan helpen bij het reduceren van mogelijke fouten en vooroordelen in het menselijk redeneerproces. In die zin zijn goede representaties dus te zien als ondersteunende hulpmiddelen voor communicatieprocessen die zitten ingebed in beslissingsprocessen. De vraag die hier uit voorkomt is logischerwijze wat nu eigenlijk "goede" representaties zijn. Daarover is veel onderzoek gepubliceerd, met name op het gebied van verschillende visualisaties zoals tabellen en grafische weergaven (diagrammen, plaatjes). De resultaten zijn echter niet eenduidig in de zin dat altijd aangetoond wordt dat grafische weergaven beter zijn dan niet-grafische. Of en hoe verschillende weergaven van informatie kunnen bijdragen aan betere communicatie- en beslisprocessen is dus, zoals al eerder gezegd, de centrale vraag in deze dissertatie.

De bovengeschetste context is nog puur conceptueel en theoretisch. Om daadwerkelijk onderzoek mogelijk te maken moet de feitelijke omgeving ontworpen en gebouwd worden. Hiervoor is gebruik gemaakt van het kennismanagement simulatiespel KM Quest, dat een van de producten was van een door de EU gefinancierd R&D project. In KM Quest moet een team van maximaal drie personen gedurende en periode van 3 jaar de kennishuishouding van een fictief bedrijf, Coltec, aansturen. Hierbij maken ze gebruik van een simulatieleeromgeving die als belangrijkste componenten een procedureel kennismanagement model en een simulatiemodel van het bedrijf Coltec bevat. In deze omgeving doorlopen ze gedurende maximaal 12 kwartalen de cyclus van beslissen over te nemen interventies in het bedrijf - het in ogenschouw nemen van de effecten van die interventies alsmede externe en interne gebeurtenissen die de kennishouding kunnen beïnvloeden - het opnieuw beslissen over interventies. In elke beslisstap in deze cyclus kunnen ze gebruik maken van het kennismanagement model om het proces te sturen. De effecten van interventies worden zichtbaar gemaakt door de waarden van een groot aantal indicatoren, 82 in totaal. Deze indicatoren geven informatie over verschillende aspecten van het bedrijf zoals marktaandeel en winst, maar ook over specifieke kennismanagement relevante grootheden zoals kennisontwikkeling op het gebied van marketing, kennisgebruik op het gebied van productie en competentie op de verschillende kennisgebieden. Alle communicatie tussen de spelers gaat via een chat systeem dat alleen tekstgebaseerde communicatie toestaat. Tijdens het spelen hebben de spelers elk toegang tot de informatie op hun eigen scherm. Het is duidelijk dat het bekijken en interpreteren van 82 indicatoren bij het nemen van beslissingen wanneer communicatie alleen via chat verloopt geen eenvoudige zaak is. In het meest extreme geval kunnen de spelers geconfronteerd worden met een tabel van 82 indicatoren bij 12 kwartalen met in elke cel een getal, waarbij niet alle getallen in dezelfde eenheid zijn. Sommige zijn in geld (miljoenen Euro's), andere zijn in absolute aantallen (aantallen personeelsleden), sommige in percentages (marktaandeel) en een substantieel deel is in de vorm van relatieve cijfers op een schaal van 1 tot 10. Door middel van het toepassen van een groot aantal ontwerpprincipes zijn voor alle variabelen visuele representaties gemaakt die tot doel hebben het interpreteren van de (grote aantallen) cijfers te vereenvoudigen. Gebruik is onder andere gemaakt van lijndiagrammen, staafdiagrammen, iconen, kleur en een kenniskaart die in één oogopslag de waarden (en de verandering daarvan) van de indicatoren die het meest relevant zijn voor kennismanagement laat zien in een compacte representatie. De centrale hypothese is dat het beschikken over deze visuele ondersteuning zal leiden tot betere communicatie- en beslisprocessen dan wanneer men niet over deze visuele hulpmiddelen beschikt.

Om deze centrale hypothese te onderzoeken zijn drie studies uitgevoerd. De eerste pilot studie had als doelen het nagaan of de ontworpen visuele ondersteuning door spelers begrepen werd, wat de rol van de indicatoren was in het beslisproces, of de spelers daadwerkelijk probeerden de informatie gezamenlijk te verwerken en het uittesten van enkele meetinstrumenten en de algemene opzet voor de twee andere experimenten. Gebruik werd gemaakt van een beperkte versie van KM Quest, waarin het daadwerkelijke simulatiemodel ontbrak en effecten van interventies a-priori waren vastgelegd. Ook de chat faciliteit was niet geïntegreerd in het systeem en moest apart benaderd worden. Verder werd slechts een deel (31) van het totaal aantal indicatoren gebruikt. Er werden twee condities gecreëerd: in de ene conditie kregen de spelers alleen de beschikking over informatie in de vorm van een tabel met getallen, in de andere conditie kregen de spelers alle informatie over de waarden van de indicatoren aangeboden in de vorm van grafische representaties (diagrammen). In elke conditie werden respectievelijk 4 en 3 teams van elk drie spelers gevormd. Om te controleren voor verschillen in bekwaamheid in het interpreteren van grafische informatie werd een test afgenomen. Verder werd via een test die bestond uit drie delen, de tevredenheid met het beslissen gemeten (tevredenheid met het proces, tevredenheid met de uitkomsten, tevredenheid met de ondersteuning). Alle chat's werden gelogd en de logfiles werden gebruikt voor het analyseren van de communicatieprocessen. Tot slot werden uit elke conditie twee spelers geselecteerd voor een interview achteraf. Over de hele linie werden de grafische representaties positief beoordeeld, op enkele punten konden verbeteringen worden aangebracht in het ontwerp. Tijdens het spelen zochten de spelers regelmatig toegang tot de indicatoren, maar er was niet veel verschil tussen de twee condities. Wat betreft het gebruik van de informatie in de communicatieprocessen, dit kon geclassificeerd worden in een aantal categorieën die liepen van geen gebruik van informatie over de waarde van de indicatoren tot gebruik waarbij gepoogd wordt een gebeurtenis in het spel via het interpreteren van de waarden van indicatoren te relateren aan de selectie van een interventie. Deze laatste categorie kan gezien worden als de meest intensieve vorm van communicatie en samenwerking, maar dit kwam nauwelijks voor. De spelers in de conditie die alleen toegang had tot de grafische informatie was meer tevreden met het groepsbeslisproces, dit gold in het bijzonder voor de tevredenheid met de ondersteuning voor het beslisproces. De opzet van het onderzoek en de gebruikte meetinstrumenten bleken te voldoen voor de twee volgende studies. Geïntegreerde implementatie van de chat faciliteit bleek absoluut noodzakelijk te zijn. Meer in het algemeen kwam uit deze pilot studie naar voren dat er een sterke tendens bij spelers is om een aanpak te kiezen die erop neer komt om een door het systeem gepresenteerde gebeurtenis direct te vertalen in een interventie die bedoeld is om iets aan de mogelijke gevolgen ervan te doen.

De tweede studie was een compleet experiment waarin het effect van visualisatie op communicatie- en beslisprocessen werd onderzocht. Tevens werd meegenomen in hoeverre deze processen samenhangen met betere leeruitkomsten bij de spelers. Er werden drie experimentele condities gevormd, in de eerste conditie hadden de spelers alleen de beschikking over de tabel met getallen (T conditie), in de tweede conditie hadden de spelers alleen de beschikking over de grafische weergave (C conditie) en in de derde conditie, die overeenkomt met de basismanier waarop KM Quest gespeeld wordt, hadden de spelers de beschikking over zowel de tabel met getallen als met de grafische weergaven (TC conditie). Gebaseerd op het theoretisch kader werd voorspeld dat voor de te meten variabelen (effectiviteit van het communicatieproces, kwaliteit van de uitkomsten van het communicatieproces, aantal gerealiseerde beslissingen, tevredenheid met het beslisproces, leerresultaten) de TC conditie het beter zou doen dan de C conditie en de C conditie beter dan de T conditie. In elke conditie werden 3 teams van 3 spelers gevormd (N=27) die elk maximaal 9 kwartalen moesten spelen. Wanneer we elk kwartaal zien als een nieuw beslisproces met ingebedde communicatieprocessen is er sprake van de observatie van maximaal 81 beslissituaties. Als meetinstrumenten werd gebruikt maakt van de tests uit de pilot studie, de logfiles en een bestaande kennistest voor KM Quest die zowel voor als na het experiment werd afgenomen. Uit de test voor het meten van verschillen in bekwaamheid van het interpreteren van grafische informatie bleek dat alle condities een gelijke en hoge mate van bekwaamheid hadden. Verschillen tussen condities zijn dus niet terug te voeren op deze factor. Wat betreft de effectiviteit van het communicatieproces kwam naar voren dat de T conditie als beste uit de bus kwam. Voor de kwaliteit van de uitkomsten van het communicatieproces lag het beeld genuanceerder. Weliswaar presteerde de TC conditie het beste, maar de T conditie deed het beter dan de C conditie. Eenzelfde patroon trad op bij het aantal gerealiseerde beslissingen, maar in dit geval kwamen de T en C conditie gelijk uit. Geen verschillen werden gevonden in de tevredenheid met het beslisproces: alle condities bleken tevreden te zijn. Het meest verrassend was dat geen van de condities een leereffect vertoonde, de TC en de T conditie gaven zelfs een licht negatief leereffect te zien. Samenvattend kan geconcludeerd worden dat de voorspelde positieve effecten van visualisatie niet of nauwelijks optraden. Een mogelijke reden hiervoor is dat de spelers het spel misschien met minder inzet speelden dan verondersteld wordt in de opzet van KM Quest. Ondanks de nodige voorbereidingen bleek het aanvangsniveau van kennis op het terrein van kennismanagement erg laag te zijn. Ook uit de analyse van de communicatieprocessen kwam naar voren dat slechts zelden de informatie gebruikt werd op de manier zoals deze theoretisch gewenst is. Net als in de pilot studie bleek ook hier de neiging sterk aanwezig om de eenvoudigste cyclus te volgen: gebeurtenis - interventie om de gebeurtenis aan te pakken - door naar het volgende kwartaal. Wanneer de voorkennis onvoldoende is, kan het zijn dat de overmaat aan informatie die in de TC conditie ter beschikking staat het spelen eerder lastiger dan eenvoudiger maakt. Daarnaast bleek dat de spelers maar mondjesmaat gebruik maakten van de indicatoren voor de kennishuishouding van Coltec. Het aansturen van deze indicatoren is van cruciaal belang in het spel. Dit geringe gebruik kan te maken hebben met het feit dat deze indicatoren niet direct zichtbaar waren. Zo konden de spelers de belangrijke kenniskaart alleen bekijken door door een lange lijst van andere indicatoren te scrollen. Ook in de primaire interface lag de nadruk op het tonen van algemene indicatoren (winst, marktaandeel, klanttevredenheid). Op basis van deze bevindingen werd een tweede experiment gehouden waarin speciale aandacht werd besteed aan deze laatstgenoemde aspecten.

Dit tweede experiment had precies dezelfde opzet als het vorige, wederom drie condities (TC conditie, C conditie en T conditie) met elk 3 teams van 3 spelers. De gebruikte methoden en meetinstrumenten waren grotendeels hetzelfde en zo ook de centrale hypothesen, TC doet het beter dan C en C beter dan T op de variabelen (effectiviteit van het communicatieproces, kwaliteit van de uitkomsten van het communicatieproces, aantal gerealiseerde beslissingen, tevredenheid met het beslisproces, leerresultaten). Op twee punten werden wijzigingen aangebracht. Ten eerste werd, met het oog op de gebrekkige voorkennis in het vorige experiment, veel meer aandacht besteed aan het bijbrengen van kennis over kennismanagement en het spelen van KM Quest. Ten tweede werd de zichtbaarheid (niet de vormgeving) van de indicatoren die bijzonder belangrijk zijn voor kennismanagement verbeterd. De kenniskaart kwam, voor de TC en C condities, helemaal bovenaan de lijst te staan en in de primaire interface werden de algemene indicatoren (winst en dergelijke) vervangen door indicatoren voor het competentieniveau van Coltec op de drie relevante kennisgebieden. Wederom bleek er geen verschil te zijn in de bekwaamheid van de spelers voor het interpreteren van grafische weergaven, zij het dat het niveau iets lager was dan in het vorige experiment. Wat betreft de effectiviteit van het communicatieproces kwam naar voren dat de TC conditie het beter deed dan de C conditie en de C conditie beter dan de T conditie. Het patroon voor de uitkomsten van het communicatieproces was C beter dan T en T beter dan TC. De hoeveelheid gerealiseerde beslissingen gaf een gelijk resultaat te zien voor de T en TC conditie, terwijl beiden beter scoorden dan de T conditie. De tevredenheid met het beslissen gaf alleen een significant verschil te zien in de tevredenheid met de uitkomsten, de TC conditie was meer tevreden dan de C conditie en deze was weer meer tevreden dan de T conditie. Het meest markante verschil met het vorige experiment trad op bij de leerresultaten. Ten eerste bleek dat de betere voorbereiding geen effect had op het niveau van de voorkennis, het niveau was ongeveer hetzelfde als in het eerste experiment. Daarentegen werd er wel een significant leereffect gevonden voor alle condities. Alleen voor wat betreft strategische kennis was er een verschil tussen de condities met dien verstande dat de T conditie het hier slechter deed. Samenvattend kan gesteld worden dat ook in het tweede experiment niet duidelijk aangetoond kon worden dat een combinatie van tabellen en grafische weergaven of grafische weergaven alleen, het beter doen dan een tabel onder de conditie van communicatie tussen groepsleden via een middel met beperkte bandbreedte (chat). Kennelijk leidt een combinatie van een betere voorbereiding en een betere zichtbaarheid van voor kennismanagement bijzonder relevante indicatoren tot significante leereffecten. Aan welke van deze twee factoren dat precies valt toe te schrijven kan op basis van dit experiment niet gezegd worden. Theoretisch gezien is het wel duidelijk dat tevredenheid met het beslissen, zoals gemeten in drie aspecten, geen relatie heeft met de kwaliteit van de communicatieprocessen enerzijds en bereikte leerresultaten anderzijds. In beide experiment was de tevredenheid hoog en nauwelijks verschillend tussen de condities.

Vatten we tenslotte de resultaten van deze dissertatie samen dan kunnen we zeggen dat het veronderstelde positieve effect van visuele hulpmiddelen bij het verbeteren van communicatie- en beslissingsprocessen bij geografisch verspreide beslissers die moeten samenwerken in een context van een beperkte communicatiebandbreedte, niet overtuigend kon worden aangetoond. Vanuit een ontwerp perspectief leidt dit tot de aanbeveling om niet zonder meer te opteren voor geavanceerde grafische representaties, ook tabellen kunnen effectief zijn. Ook een combinatie van tabellen en grafische representaties dient met zorg overwogen te worden, het gevaar van teveel informatie die eerder verwarrend dan verhelderend werkt ligt hier op de loer. Wanneer men streeft naar leereffecten in een KM Quest context is een adequate voorbereidingsfase essentieel. Hoewel dit niet direct de a-priori kennis verhoogt, leidt het wel tot veel betere leerresultaten na het spelen van het spel.