

Supporting Medical Decision Making with Collaborative Tools

Jingyan Lu

Major in Cognition and Instruction
Department of Educational and Counselling Psychology
McGill University
Montreal, Canada

A thesis Submitted to the Faculty of Graduate Studies and Research in Partial Fulfillment
of the Requirements for the degree of Ph.D. in Educational Psychology

© Jingyan Lu, 2007



Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-38607-1
Our file Notre référence
ISBN: 978-0-494-38607-1

NOTICE:

The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protègent cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.


Canada

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor, Professor Susanne Lajoie for her patient guidance, consistent encouragement and financial support, all of which kept me motivated and focused on my study all these years. Without her support this work would be impossible.

I would like to thank my committee members for taking the time to guide me through the dissertation. I would like to thank Dr. Jeffrey Wiseman for leading me to this interesting area with his openness, his enthusiasm and his insight into medical education. I am also grateful to Prof. Robert Bracewell for his insightful remarks and valuable comments.

I am grateful to my colleagues both in and out of the applied cognitive lab: Erika Franz, Vicky Tung, Zhidong Zhang, and Cheryl Cook for their valuable discussions, suggestions, and proof readings.

I would also like to acknowledge the financial support provided by FQRSC (Fonds de recherche sur la société et la culture).

This thesis would not have materialized but for the help of Tom Patrick. As a friend and colleague, he has helped me continuously, contributing tremendous amounts of time in helping me collect and transcribe data, discuss ideas and in proof reading my thesis. I consider it my fortune to be his friend and to have worked with him.

Finally I would like to thank my husband Ai Yu for taking care of the family while I had to meet paper deadlines or be away at conferences. Justin, I would also like to thank you not only for getting me to understand the meaning of life, but also for forcing me to learn to manage time more efficiently.

ABSTRACT

This study examines the decision-making activities and communicative activities of two groups participating in a simulated medical emergency activity: the control group (CG) using a traditional whiteboard and the experimental group (EG) using a structured interactive whiteboard. The two groups differ in that the EG has a structured template to annotate and share their arguments with each other. Data analysis of the decision-making activities focused on planning, data collecting, managing, and interpreting patient data. Data analysis of the communicative activities focused on informative, argumentative, elicitive, responsive, and directive acts. In the early stage of decision-making the EG spent significantly more time interpreting the situation and less time managing the patient than the CG; in the later stage the EG spent significantly more time managing the patient but less time interpreting the situation. No significant results were found in communicative activities due to low cell frequencies of the utterances. Qualitative results indicated that shared visualizations can disambiguate and clarify verbal interactions and promote productive argumentation and negotiation activities. Shared cognition facilitates the construction of shared situation models and joint problem spaces which lead to better decision making and problem solving.

RÉSUMÉ

Cette étude examine les activités de la prise de décision et de la communication entre deux groupes participants dans une simulation médicale de secours: un groupe de commande (CG.) utilisant un tableau blanc traditionnel et un groupe expérimental (EG) utilisant un tableau blanc interactif structuré. Les deux groupes se distinguent quant aux variables de communication, car le EG possède une manière structurée pour échanger et pour considérer leurs opinions entre les membres du groupe. L'analyse des données des activités de la prise de décision se concentre sur la planification, le rassemblement des données, le contrôle, et l'interprétation des données de patients ; alors que l'analyse de données des activités de la communication se concentre sur instructif, raisonné, elicitive, sensible, et la directive. Des résultats significatifs expliquent le phénomène suivant : au lieu de contrôler les patients, le EG dépense plus de temps à interpréter la situation que le CG dans les premières phases de la prise de décision. Plus tard, ils dépensent plus de temps à contrôler les patients mais moins de temps à interpréter la situation. Aucun résultat significatif n'a été trouvé quant aux activités de la communication à cause de la basse fréquence de cellules de l'expression. Des résultats qualitatifs montrent que la visualisation partagée puisse désambiguïser et clarifier l'interaction verbale et favoriser l'argumentation et la négociation productives. Une connaissance partagée facilite la construction des modèles et espaces commun de problème qui mènent à une meilleure résolution de problèmes et de la prise de décision.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	i
ABSTRACT	ii
RÉSUMÉ	iii
TABLE OF CONTENTS	iv
LIST OF TABLES.....	viii
LIST OF FIGURES	ix
LIST OF APPENDICES.....	x
Chapter 1: Introduction.....	1
1.1 Background.....	1
1.2 Research Questions.....	3
Chapter 2: Literature Review.....	5
2.1 Problem Solving and Decision-making	5
2.1.1 Medical Problem Solving	5
2.1.1.1 Reasoning strategies	7
2.1.1.2 Knowledge representation	9
2.1.1.3 Other issues of problem solving	11
2.1.2 Decision Making.....	12
2.1.2.1 Classical decision making.....	13
2.1.2.2 Naturalistic decision making	14
2.1.2.3 Collaborative NDM	17
2.2 Collaborative Learning	19
2.2.1 Definition.....	19

2.2.2 Three Collaborative Learning Perspectives.....	20
2.2.2.1 Situated cognition	20
2.2.2.2 Shared cognition	22
2.2.2.3 Distributed cognition	23
2.2.3 Collaborative Problem Solving.....	25
2.3 Collaborative Learning Tools	27
2.3.1 Three Well-recognized Collaborative Tools	28
2.3.2 Framework of Collaborative Tools.....	36
2.3.1.1 Visualization tools	37
2.3.1.2 Argumentation tools	39
2.3.1.3. Management tools.....	42
2.4 Summary.....	49
Chapter 3: Methodology	51
3.1 Subjects.....	51
3.2 Description of Learning Activity	51
3.2.1 Traditional Learning Activity	52
3.2.2 Features Added in the Current Study.....	58
3.3 Research Design	60
3.3.1 Classroom Activity	60
3.3.2 Post Test.....	63
3.4 Cognitive Framework of Collaborative Decision-Making Processes.....	63
3.5 Equipment and Software.....	64
3.5.1 Interactive Whiteboard Technology	64

3.5.1.1 Shared visualization tools	65
3.5.1.2 Collaborative argumentation tools	66
3.5.2 Dropdown Menu	67
3.6 Data Analysis	68
3.6.1 Records of Classroom Discourse and Decision-making Activities	69
3.6.1.1 Decision-making activities	69
3.6.1.2 Communicative activities	71
3.6.2 Computer Records	76
3.6.3 Post Test — semi-structured interview	76
3.6.4 Microanalytic Method	79
3.6.5 Data management and analysis	79
Chapter 4: Results	82
4.1 Decision-making Activities	82
4.1.1 Model selection	83
4.1.2 Post hoc test	85
4.2 Communication Activities	90
4.3 Argumentation Activities	92
4.4 Post Test	95
4.5 Decision-making, Communicative, and Argumentative Activities	96
4.5.1 DMA and CA at Different Stage	97
4.5.2 Content of Communication	106
4.5.3 Pattern of Interaction	108
4.6 Summary	110

Chapter 5: Discussion	111
5.1 Characteristics of Collaborative Decision-making in Emergency Situations.....	111
5.2 Multiple Perspectives.....	114
5.3 Decision-making, Communication, and Cognitive Tools	115
5.4 Role of Collaborative Tools.....	123
5.4.1 Interactive Whiteboards — as a Medium and as Stimuli for Communication.....	123
5.4.2 Interactive Whiteboard — as Cognitive Tools to Scaffold Communication and Problem Solving	124
5.4.3 Electronic Algorithm — Dropdown Menu.....	126
5.5 Naturalistic Decision-making (NDM)	127
5.6 Limitations of the Study	129
5.7 Directions for Future Research	131
5.8 Contributions	134
5.9 Summary.....	136
REFERENCE	138

LIST OF TABLES

Table 2.1. Summary of Three CSCL Environments.....	29
Table 3.1. Summaries of Teaching Activities and analysis in Traditional, Control, and Experimental Group.....	59
Table 3.2. Decision-making Activity Coding Categories.....	71
Table 3.3. Categories Describing Communicative Activities	74
Table 3.4. Coding of Post Teaching Interview	78
Table 3.5. Time (in minutes) Spent by Each SG across Different Sessions.....	81
Table 4.1. Selected output of Model Selection: Saturated Model.	84
Table 4.3. Frequency Distribution in Group*DMA.	86
Table 4.4. Frequency Distribution in Group*Session*DMA.	87
Table 4.5. Frequency Distribution in Group*DMS*DMA.....	87
Table 4.7. Frequency Distribution of Group*CA.....	91
Table 4.8. Frequency Distribution of Group*DMS*CA.	91
Table 4.9. Frequency Distribution of Group*Session*CA.....	92
Table 4.10. 2-way ANOVA Output for Group*DMA.	96

LIST OF FIGURES

Figure 2.1. Belvedere Inquiry Diagram	31
Figure 2.2. PIE Interface.....	32
Figure 2.3. PREP Editor Interface	33
Figure 2.4. Framework of collaborative tools	48
Figure 3.1. Procedures in “deteriorating patient”	53
Figure 3.2. The teacher is updating patient’s vital signs and mental states.....	55
Figure 3.3. Three-step framework for approaching medical emergencies	57
Figure 3.4. Snapshots of experimental and control groups.	62
Figure 3.5. Procedures in collaborative decision-making.....	64
Figure 3.6. Screenshot of eBeam whiteboard	67
Figure 3.7. Screen shot of dropdown menu.	68
Figure 4.1. Frequency distribution of Group*DMS*DMA	88
Figure 5.1. Relationship between Collaborative tools, Communication, and Decision making.	122

LIST OF APPENDICES

Appendix 1: An Except from the Experimental Group.....	164
Appendix 2: Instruction for the Interview.....	165
Appendix 3: Transcripts of the Clinical Case of the Interview.....	166
Appendix 4: Informed Consent Form.....	171
Appendix 5: Text-based Emergency Algorithm.....	172
Appendix 6: Ethical approval from Ethics Review Board.....	177
Appendix 7: Complete output of Saturated model	178

Chapter 1: Introduction

1.1 Background

The dynamic and complex nature of emergency medical care arises from the fact that patients often suffer from multiple potentially life-threatening problems which in turn imposes intense cognitive demands on doctors, nurses, and other health care professionals, who are called upon to make fast and accurate decisions.

The study of naturalistic decision making (NDM) focuses on decision making in natural as opposed to laboratory settings. This area of research grew out of studies of how military personnel make decisions under extreme time pressure (Klein, Calderwood, & Clinton-Cirocco, 1986) and has since been extended to the study of commercial and military aviators, fire fighters and emergency medical care personnel who must make fast and accurate high stakes decisions in dynamic high risk settings (Cannon-Bowers & Salas, 1998; Lajoie, Azevedo, & Fleischer, 1998; Orasanu & Connolly, 1993).

Decision-makers in NDM usually work as a team: they contribute to and rely on shared goals and background knowledge, effective communication, situational awareness, and meta-cognitive skills to make fast, effective decisions with incomplete or conflicting information in a rapidly-changing setting (Orasanu, 2005). Because emergency medical care typically involves teams of medical decision makers working in highly organized environments to quickly and accurately assess the highly volatile medical conditions of patients, they need to be able to communicate effectively with each other and perhaps with experts from other hospital departments. This in turn facilitates the construction of shared understandings of goals, plans, and actions.

To prepare medical students to make fast and accurate decisions in emergency

care situations, a learning activity called ‘the deteriorating patient’ was designed by Dr. Jeffrey Wiseman (personal communication, November 24, 2005) to allow medical students to role play in simulated medical emergencies. The goal of the activity is to learn how to apply a framework to stabilize the patient whose symptoms grow increasingly life threatening as the scenario progresses. Different students in the class play the medical student, the junior resident and the senior resident. Students try to stabilize the deteriorating patient as quickly as possible. The deteriorating patient is seen first by the “medical student”, who then calls the “junior resident” when he or she reaches an impasse who finally calls the “senior resident” when he or she needs assistance. The teacher may alternate between the roles of the patient and the nurse. As the patient, he enacts dramatically his/her deteriorating physical conditions. As the duty nurse, he carries out student orders, reports results and updates patient’s deteriorating vital signs and symptoms. Students determine what to do by questioning the nurse, as well as each other and by observing the patient.

This study was designed to support the deteriorating patient activity with technology to facilitate NDM in collaborative learning settings. Computers and networks can support collaborative learning with argumentation, visualization, and management tools (Lu & Lajoie, 2005). In this study, a tool to support argumentation and visualization was designed and implemented using an interactive whiteboard (IW).

Computer-based argumentation tools can structure student interactions which can improve subject matter orientation, reduce off-task interaction, and lead to discussions that are more coherent, focused and productive (Hron, Hesse, Cress, & Giovis, 2000).

The visual representations of arguments can serve as external frames for constructing knowledge and solving problems (Roschelle & Teasley, 1995).

Structured annotation tools were designed in the IW to allow students to comment on the decisions by other participants in the activity and to propose further moves. The IW tools were designed to scaffold collaborative decision-making processes by promoting productive discussions of various proposed actions and plans in a structured patient chart. Shared visualization tools facilitate collaborative decision-making by enabling students to construct joint problem spaces. IW can display actions of the participating and observing students in real time.

1.2 Research Questions

This study examines decision-making activities and communicative activities in two groups: the control group (CG) that uses a traditional whiteboard and the experimental group (EG) that uses an IW designed for the deteriorating patient activity. In both groups, students communicate their plans, actions, and interpretations with respect to the deteriorating patient and construct a shared understanding of the problem in order to enhance their decisions-making. The CG involves only face-to-face collaboration during which student collect patient information and manage patient. Once students collect information the instructor record it in written on the traditional whiteboard in the form of a patient chart based on which following students continue to develop their decision-making actions. The CG students have no annotation tools. The EG involves face-to-face collaboration, online collaboration via IW technology, and use of annotation tools. IW was designed not only to allow decision-makers to collect, manage, share, and retrieve patient's information on the patient chart electronically, but also to allow

observers to participate in the decision-making process by typing comments into a column of the patient data chart. The use of argumentation tools allows students to annotate and develop arguments based on the collection of patient data and patient management activities during the deteriorating patient learning activity. This study will focus on answering the following five research questions:

1. Do the CG and EG student decision making activities differ?
2. Do the CG and EG student communicative activities differ?
3. What are the argumentation activity characteristics of EG student annotation?
4. Do the CG and EG student post teaching problem solving interviews differ?
5. Why do CG and EG student decision-making and communicative activities differ?

Chapter 2: Literature Review

Given the collaborative nature of emergency medicine and the nature of problem solving in such contexts, and the emerging importance of computers in teaching and learning environments, several literatures will be reviewed: problem solving and decision-making, collaborative learning perspectives, and computers as collaborative tools.

2.1 Problem Solving and Decision-making

Problem solving and decision-making are major research themes in medical cognition and are often dealt with in tandem where problem solving involves goals, strategies and actions for solving problems, and decision making refers to ultimate solutions. For example, Simon and associates (1986) found that both problem solving and decision making are two essential components of governmental and economic activities where problem solving typically involves fixing agendas, setting goals, and designing actions, and decision making involves choosing and evaluating solutions. Although highly related and sometimes used interchangeably, problem solving and decision-making do have unique research paradigms. Consequently, the following sections will describe and compare medical problem solving and decision making. The review of medical problem solving focuses on medical reasoning strategies and knowledge representation. The review of decision-making focuses on naturalistic and collaborative decision making as opposed to classical decision-making.

2.1.1 Medical Problem Solving

Studies of medical problem solving began in the late 1960s with the recognition of the importance of reasoning and problem solving in the highly complex and uncertain

domain of medical diagnosis and decision-making (Elstein, Shulman, & Sprafka, 1978). Elstein and his colleagues used simulated patients and think-aloud protocols to explore the problem solving procedures of physicians at different levels of expertise. Problem solving studies were influenced by research on expertise (Newell & Simon, 1972). Glaser and Chi (1988) cite the following characteristics of expertise: experts (a) excel mainly in their own domains, (b) perceive larger meaningful patterns in their domains, (c) are faster at performing domain skills and solving problems with fewer errors, (d) have superior long- and short-term memory, and (e) see and represent problems in their domain at deeper or more principled levels than novices who tend to represent problems at more superficial or less principled levels.

Medical problems-solving studies have found experts to share five common characteristics:

1. Experts have specialized domain knowledge. A cardiologist has specialized knowledge in the domain of cardiology as opposed to that of endocrinology, Novices have everyday knowledge of a domain or the prerequisite knowledge assumed by the domain, i.e., medical students (Patel & Groen, 1991).
2. Experts are better able than novices to select relevant and critical cues and to disregard irrelevant cues (Lesgold, Robinson, Feltovich, Glaser, Klopfer, & Wang, 1988).
3. Experts execute general plans more quickly (Lesgold et al., 1988).
4. Experts have better recall of relevant medical cases than novices (Patel & Groen, 1991),

5. Experts organize their domain knowledge into concise, hierarchical structures while novices organize their knowledge into flat, superficial structures (Patel, Arocha, & Kaufman, 1994).

Medical expertise research focuses on how various cognitive processes are related to experts and physicians at different levels of expertise. For instance, Patel and colleagues (Patel et al., 1994) found that different reasoning strategies and associated knowledge representations during problem solving are associated with differences in expertise. In addition, other cognitive processes such as hypothesis generation (Joseph & Patel, 1990), evidence selection (Arocha, Patel, & Patel, 1993), search strategies (Lesgold et al., 1988), and knowledge use (Lesgold et al., 1988), have been examined in medical problem solving. The sections directly following will mainly focus on reasoning strategies and knowledge representation which are central to medical problem solving.

2.1.1.1 Reasoning strategies

Medical problem solving studies have identified and used two types of reasoning strategies to differentiate experts and novices: forward or data-driven reasoning and backward or hypothesis-driven reasoning (Patel & Groen, 1986; Schwartz, 2000). Forward reasoning involves drawing inferences from such available data as patient symptoms and in medicine is used by experts working in their specialties. Backward reasoning involves breaking down larger problems into smaller ones and collecting data based on hypotheses and is typically used by novices although experts may also use it in diagnosing diseases from outside their areas of specialization (Patel & Groen, 1991). The fact that experts use forward reasoning to solve problems from their domains of expertise suggests that it requires highly organized domain knowledge. This is similar to 'pattern

recognition' in such domains as chess (Newell & Simon, 1972). Forward reasoning also enables experts to draw conclusions quickly from meaningful data unlike novices who tend to rely on backward reasoning which is more time consuming. Because backward reasoning is less knowledge dependent it is most appropriate when domain knowledge is inadequate (Patel & Groen, 1991).

Forward and backward reasoning have been extensively investigated in different medical domains and at different levels of expertise. Some subtle differences have been found to exist between the two forms of reasoning. For example, Patel and her colleagues (Patel & Groen, 1986; Patel, Groen, & Arocha, 1990) found that sub-experts (individuals with generic knowledge but inadequate specialized domain knowledge, i.e. endocrinologists solving cardiology problems) tend to use a mixture of forward and backward reasoning when they are unsure of the diagnosis. This suggests that directionality of reasoning is related to diagnostic accuracy (Patel & Groen, 1986). In their study of the diagnostic reasoning of radiologists, Lesgold and colleagues (Lesgold et al., 1988) found that neither backward reasoning nor forward reasoning predominated. Rather, they found reasoning to be a multi-step process where an initial perceptual decision was made, producing a differential diagnosis set with associated probabilities triggering cognitive processes to resolve ambiguities, either by searching for initially overlooked perceptual features or by considering other data sources such as medical history and diagnostic tests. This multi-step reasoning process can be characterized as schema-driven. It incorporates characteristics of both forward and backward reasoning into a recursive, interactive decision-making process which includes abnormality location, abnormality feature characterization, anatomical location, medical explanation, and

overall case resolution. In a study of diagnostic reasoning in mammography, Azevedo (1997; Azevedo & Lajoie, 1998) identified different findings from Lesgold. He found that both staff and residents used forward reasoning and schema-driven problem solving strategies. Protocol analysis indicated that diagnostic reasoning of mammography is characterized by (a) the predominant use of forward reasoning diagnostic strategies, (b) the use of backward reasoning strategies, or a combination of both strategies depending on case typicality and clinical experience, and (c) rapid schema-based problem solving to facilitate search, to characterize mammography features, to integrate clinical theory cues, and to accurately diagnose and to make subsequent recommendations.

2.1.1.2 Knowledge representation

Knowledge representation involves the nature and structure of knowledge (Markman, 1999) which provides a basis for characterizing problem-solving processes. Problem solving can be described as the organization of declarative and procedural knowledge. Experts make greater use of their procedural knowledge as opposed to their declarative knowledge, which is less reliable and less quickly executed because it must be activated and retrieved from memory (Lesgold, 1988). These findings are consistent with Anderson's (1982) 'stage learning theory' according to which the acquisition of expertise involves three stages: (a) the declarative knowledge stage; (b) the knowledge compilation stage; and (c) the procedural stages. Traditional medical curricula reflect these stages in its two-stage training that facilitates medical problem solving: (a) rule-based learning, where students learn through textbooks and lectures, and (b) experience-based learning, where they learn through exposure to real patients (Schmidt, Dauphinee, & Patel, 1987). These two stages depend on two types of knowledge: (a) basic science (biochemistry,

anatomy, and physiology) and clinical (knowledge of diseases and associated findings) knowledge, and (b) clinical experience based knowledge (knowledge of findings related to diseases). As expertise develops, the acquisition of problem solving skills and knowledge relies more and more on clinical experience.

There are three theories about how medical knowledge is structured: (a) small world theory, (b) schema theory, and (c) illness scripts theory. Small world theory proposes that expert knowledge is organized on the basis of similarities between disease categories, which form small worlds of knowledge consisting of subsets of diseases and their distinguishing features (Kushniruk, Patel, & Marley, 1998). According to small world theory, in the diagnostic process, physicians focus on relatively small sets of logically related diseases. Diseases in the same 'small worlds' typically share overlapping features, which facilitate discrimination based on the presence or absence of key medical findings. Networks produced by medical experts were found to contain a limited number of tightly connected hypotheses and findings, displaying a high degree of coherence and relatedness. It is argued that expert knowledge is organized in this way because of limitations of human memory and processing capacity (Kushniruk et al., 1998).

According to schema theory, schemas, which are defined as hypothetical cognitive structures, allow people to access past experiences and knowledge in interpreting present situations. Schemas support the quick identification of relevant information and help filter out irrelevant information (Brewer & Nakamura, 1984). Expert schemas facilitate pattern recognition and support coherent and efficient testing procedures, allowing for discrimination among competing diagnoses in processes of reasoning and decision-making. The completeness of schemas is a critical factor

influencing diagnostic accuracy (Feltovich, Johnson, Moller, & Swanson, 1984; Johnson, Duran, Hassebrock, Moller, Prietula, Feltovich, & Swanson, 1981). Studies in radiological diagnoses indicate that reasoning is schema driven and experts possess better organized schemas than novices (Lesgold et al., 1988).

Illness scripts are hypothesized general knowledge structures that has three components: enabling conditions, faults, and consequences (Custers, Boshuizen, & Schmidt, 1998; Feltovich et al., 1984; Schmidt & Boushuizen, 1993). Enabling conditions are contextual factors and patient background factors that influence the probability of someone getting a disease. Faults are the pathophysiological malfunctions of diseases and consequences are clinical symptoms of diseases. Illness scripts are developed through continuous exposure to patients. They might contain little knowledge of pathophysiological causes of symptoms and complaints, but they do contain a wealth of clinically relevant information about diseases, their consequences and the contexts in which they develop.

In summary, reasoning and knowledge representation are important and associated aspects of problem solving. Forward reasoning suggests that experts have sufficient knowledge which is arranged into efficient patterns that help them in their problem solving.

2.1.1.3 Other issues of problem solving

Other problem solving issues include hypothesis generation, evidence selection, and knowledge use. The literature suggests that experts generate fewer and more general hypotheses at an earlier stage of problem solving than do novices or intermediates (Joseph & Patel, 1990; Patel et al., 1994; Sisson, Donnelly, Hess, & Woolliscroft, 1991).

Experts tend to use breadth first reasoning while novices tend to use depth first reasoning (Arocha et al., 1993; Patel et al., 1994). Further, experts are better able to focus on relevant information and to disregard irrelevant information and are more likely to change their hypotheses to fit case information (Joseph & Patel, 1990; Lesgold et al., 1988). Biomedical knowledge is used differently in different domains and in different tasks by individuals with different levels of expertise (Lesgold et al., 1988; Patel & Groen, 1986). For instance, experts seldom use biomedical knowledge to explain their diagnoses (Patel et al., 1990).

This section has described the characteristics of reasoning strategies and knowledge representation in medical problem solving. The next section will describe the characteristics of decision-making in medical domains.

2.1.2 Decision Making

Early decision making studies focused on contrasting the decisions that subjects made based on sets of fixed alternatives with normative models based on probability theory that indicate optimal choices under conditions of uncertainty (Camerer & Johnson, 1991). The types of decisions are constrained by the alternatives offered unlike the real-world situation. In real-world situations, decisions are embedded in broader contexts and are part of decision-action cycles that are affected by monitoring and feedback rather than by individual isolated judgments. Rather than simply making the best choices, making real-world decisions involves satisfying numerous complex conditions (Orasanu & Connolly, 1993). Decision making in the former situation is called classical decision making and in the latter situation it is called naturalistic decision-making. The following

sections will introduce these two decision-making theories but will concentrate on the latter which is the focus of this study.

2.1.2.1 Classical decision making

Classical decision making focuses on the products rather than the processes of reasoning. According to Beach and Lipshitz (1993), the theory refers to a collection of:

axiomatic models of uncertainty and risk (probability theory, including Bayesian theory) and utility (including multi-attribute theory), that prescribe the optimal choice of a option from an array of options, where optimality is defined by underlying models and the choice is dictated by an explicit rule, usually some variation of maximization of (subjective) expected utility. (p. 21)

In a recent review, Elstein and Schwarz (2002) characterized decision making as making diagnoses using Bayes's theorem to update collected evidence. They claimed that:

The standard rule for this task is Bayes's theorem. The pretest probability is either the known prevalence of the disease or the clinician's subjective impression of the probability of disease before new information is acquired. The post-test probability, the probability of disease given new information, is a function of two variables, pretest probability and the strength of the evidence, measure by a likelihood ratio. (p. 730)

Making diagnoses using Bayes' theorem is also consistent with Elstein's (2001) conceptual framework on evidence-based practice and classical decision theory which are now increasingly used to formulate medical practice guidelines.

The most influential research in the psychology of decision making was Tversky and Kahneman's (1974) work on judgment under uncertainty, which focused on the use of simplifying rules or heuristics to replace complex procedures, which were exemplified by research on heuristics and biases. Tversky and Kahneman's work strongly influenced decision research in many fields (Arkes, Dawes, & Christensen, 1986; Elstein, 1999; Heller, Saltzstein, & Caspe, 1992).

Classical decision-making studies focus on individual decisions in controlled laboratory settings or in non-urgent clinical settings with one or a few clearly defined decisions to make. However, results from such settings are difficult to use in interpreting decision-making in dynamic real-world settings. The next section will describe medical decision making in such setting.

2.1.2.2 Naturalistic decision making

Unlike classical decision making, naturalistic decision-making (NDM) takes place in the real world which is characterized by ambiguous and incomplete information. NDM research has investigated real world domains such as fire fighting, air traffic control (Orasanu & Connolly, 1993), anesthesiology (Gaba, 1992), emergency nursing telephone triage (Leprohon & Patel, 1995), surgical ICU nurse patient assessment (Lajoie et al., 1998), and physician decision-making in medical and surgical ICUs (Patel & Arocha, 2000). Whereas classical decision-making focuses on comparing and choosing among different sets of options or comparing one's decisions against rationale and standard

decisions, NDM focuses on how expert decision makers use their knowledge to make decisions in complex, real-world environments (Zsombok, 1997). It has been found that expertise in NDM requires expert domain knowledge and reasoning and involves a series of goal-directed decision-making actions (Orasanu, 2005).

Leprohon and Patel (1995) and Gaba (1992) examined NDM from the perspective of diagnostic reasoning and knowledge representation. For example, Leprohon and Patel (1995) used a retrospective think aloud technique to investigate the decision-making processes of emergency telephone triage nurses. Direction of reasoning was correlated with the levels of urgency and ambiguity. In highly and moderately urgent circumstances requiring immediate responses or little problem solving, nurses tended to use forward reasoning. In low urgent circumstances involving deliberate problem solving, nurses tended to use more backward reasoning.

Similarly, Gaba (1992) examined decision-making processes of anesthesiologists with different levels of expertise from the perspective of knowledge representation and found the expert anesthesiologists had highly organized knowledge that was a critical factor in the development of their capacity of rapid decision-making. Gaba and colleagues have developed a model of dynamic decision-making processes of anesthesiologists to create a simulation-based curriculum for training anesthesiologists (Gaba, 1996, 1999). Their course emphasizes meta-cognitive decision-making skills and the importance of real world scenarios in which people usually work in teams to provide training in NDM (Gaba, Howard, Fish, Smith, & Sowb, 2001).

NDM research has often examined decision making in emergency medical settings as they typically involve ill-structured problems, uncertain dynamic

environments, shifting, ill-defined or competing goals, action-feedback loops, time stress, high stakes, multiple participants, and organizational goals and norms (Orasanu & Connolly, 1993). The dynamic, complex, and high risk nature of critical care imposes intense cognitive demands on doctors charged with making diagnoses and treating patients. Medical personnel have little time to make decisions due to such facts as time-pressure, distractions, and the extreme precariousness of patients and thus they seek to stabilize patients prior to further diagnosis. Consequently, in order to characterize the features of real-world emergency procedures, NDM researchers must focus on more action-oriented research.

Lajoie and colleagues (1998) used semi-structured interviews to investigate the clinical decision-making actions of surgical nurses. Quantitative methods revealed how different nurses arrived at the same decisions while qualitative methods revealed variability in nurses' decision-making paths. These findings, which show that medical problems can be solved in various ways and that clinical decision-making should be investigated in real world settings have also contributed to the development of computer-based learning environments (CBLEs) for broader purposes, i.e., surgical intensive care unit (SICU) (Lajoie, 2000; Lajoie & Azevedo, 2000; Lajoie et al., 1998).

Recognition-primed decision (RPD) is an important component of the NDM model (Klein, 1993). RPD describes what people do under conditions of time pressure, ambiguous information, ill-defined goals, and changing information. Like schema theory (Brewer & Nakamura, 1984) in problem solving, RPD emphasizes the importance of recognizing the cue patterns that signal particular types of problems. Unlike classical decision-making models, RPD describes how experienced decision-makers use their

experience to make good decisions without having to laboriously compare the strengths and weaknesses of alternative courses of action. To this extent, NDM has more in common with problem solving models than classical decision making one. Expert/novice studies show that experts tend to use RPD strategies in making tactical decisions while novices tend to use exhaustive analytical strategies. This suggests that novice knowledge structures are not organized systematically and they cannot recognize cue patterns (Orasanu, 2005).

Problem solving and decision-making research highlights differences between experts and novices and provides feedback on how clinical instruction can focus on improving decision-making and problem solving. Decision-making research has begun to switch its focus from decision-making outcomes to decision-making processes (Cooper & Fox, 1997). There is a convergence in the literature on decision making, problem solving, and naturalistic decision making.

Because NDM usually involves teams working together in highly organized environments, understanding how teams make decisions can help guide the design of CBLEs to facilitate collaborative decision-making. The following section will discuss the collaborative characteristics of NDM.

2.1.2.3 Collaborative NDM

NDM often involves collaboration which means that to work effectively, team members must develop shared mental models of the task at hand, shared awareness of the current situation, effective lines of communication skills, and metacognitive skills (Orasanu, 2005).

“Shared mental models” refers to shared understandings of task goals and task-relevant knowledge (Cannon-Bowers, Salas, & Converse, 1993). One example of shared mental model comes from analysis of how air crews learned to work effectively and efficiently in times of high stress (Klein, Orasanu, Calderwood, & Zsombok, 1993). Team members develop the shared understandings needed to make the decisions required to achieve long term goals through explicit communication. Such models guide daily activities and become extremely important in abnormal or emergency conditions by allowing team members to work effectively toward shared goals, without the need for continual explicit directions. Shared mental models help define problems, acceptable outcomes, and roles of team members.

“Shared situation awareness” relies on common understandings of dynamic situations and is rooted in members’ “shared mental models”. (Cannon-Bowers et al., 1993). Shared situation awareness supports effective communication which in turn facilitates the development of shared understandings. In emergent medical situations, doctors must assess and communicate rapidly changing patient conditions to other medical personnel for various reasons. This in turn facilitates the construction of shared understandings of goals, plans, and actions for managing patients.

In sum, the literature contains two perspectives in NDM research: one of them focuses on cognitive processes of decision making, such as diagnostic reasoning, knowledge structure, and decision-making actions, the other focuses on the collaborative processes through which shared understandings and situation awareness developed. The former perspective has been more fully examined because it is relatively easy to

investigate individual cognitive activities. The latter perspective has been less fully investigated due to difficulties in studying groups working in the real world settings.

Although NDM studies focused on working environments, their results can also contribute to a deeper understanding of teaching decision-making skills. To better understand collaborative processes in NDM, it is necessary to examine definitions of collaboration, theories of collaborative learning and the design of collaborative learning environments. Section 2.2 will examine the literature on collaborative learning.

2.2 Collaborative Learning

This section begins by defining collaborative learning and then reviews three collaborative learning perspectives: situated learning, shared learning, and distributed learning. The section ends with a presentation of how to examine a more complex type of collaborative learning activity, collaborative problem solving.

2.2.1 Definition

Collaborative learning refers to ‘small-group learning situations where individuals are encouraged to share their knowledge and skills with their peers as they work together on a common task or in a shared learning/training environment’ (Shute, Lajoie, & Gluck, 2000, p. 187). According to Johnson & Johnson (1989, 1999), collaborative learning provides opportunities for developing social and communication skills, positive attitudes towards peers and learning material, and for increasing motivation and group cohesion. It also promotes deeper level learning, critical thinking, shared understanding, and long term retention of the learned material (e.g., Johnson & Johnson, 1999; Slavin, 1995). Group problem solving activities are facilitated when students communicate and express their ideas because they are encouraged to explain, justify and negotiate meanings. These

effects are reinforced when collaborative learning involves authentic, complex, and ill-structured problems, which promote both the social construction of knowledge (Jonassen, 1991, 1994), and the development of higher-order thinking skills such as inductive reasoning (Lajoie, 1991).

2.2.2 Three Collaborative Learning Perspectives

There is an increasing awareness that learning should occur within authentic or meaningful situations (Brown, Collins, & Duguid, 1989; Greeno, 1998a) which call for collaboration. Such forms of learning must be considered within new frameworks. This section will discuss three such frameworks, situated learning, shared cognition, and distributed cognition, that have informed the conceptualization of collaborative learning,

2.2.2.1 Situated cognition

Lave (1991) argues that learning is normally a function of the activity, context and culture in which it occurs. For instance, language learning, tool using, and cultural adaptation are typically situated in specific contexts (Brown et al., 1989). Consequently, cognitive tasks and social tasks are inseparable. Environment is an integral part of cognitive activity and not merely a set of circumstances in which context-independent cognitive processes play out. Situated cognition or situated learning views learning as a process of entering into a 'community of practice' which is a group of individuals with different roles and experiences working together to accomplish something (Brown et al., 1989; Clancey, 1995). As newcomers or novices move from the periphery to the centre of such community, they become more active and engaged within the culture of this community and increasingly assume the role of experts (Lave & Wenger, 1991).

Situated cognition is characterized as a form of apprenticeship (Brown et al., 1989; Greeno, 1998b), which takes place within a nexus of activities, tools, and cultures. Learning, both in- and outside of school, advances through collaborative social interaction and involves the social construction of knowledge. When applied in the classroom, the principles of situated cognition call for authentic learning activities in which knowledge is dynamically and collaboratively constructed. Activity, participation, and cognition are codependent and are a function of the ecology of the entire community (Lemke, 1997).

Educational researchers are not the only ones interested in situated cognition. Researchers in artificial intelligence (AI) also use it in modeling human 'cognition' and in building 'intelligent' machines. AI describes situated cognition as 'the study of how human knowledge develops as a means of coordinating activity *within activity itself*. This means that feedback, which occurs internally and within the environment over time, is of paramount importance. Knowledge is dynamic in both formation and content' (Clancey, 1997, p. 4). Both educational and AI researchers understand the importance of context in knowledge acquisition. In addition, both agree that situated cognition not only refers to how groups of individuals interact with one another and their surroundings, but also how feedback mechanisms are used and built on prior knowledge to direct behavior and guide the formation of new knowledge.

Models of situated cognition that emphasize the importance of context and individualized and adaptive (dynamic) feedback are consistent with models of NDM. In emergency medicine, the cognitive processes and actions of doctors are situated in specific contexts, which include the patient's situation and the institutional environment,

e.g., medical equipment, laboratory tests, senior medical staff serving as consultants. Such dynamically evolving contexts continually influence and are influenced by the cognitive activities of medical personnel.

2.2.2.2 Shared cognition

Shared cognition views learning as an integral part of the environment. Instead of focusing on individual cognitive processes, it focuses on the social processes. Socially shared meanings cannot be reduced to mental representations, but rather arise among groups of learners through verbal and non-verbal communication and socially shared artifacts (Resnick, Levine, & Teasley, 1991). Shared cognition implies that knowledge and skills should be acquired in the contexts in which they apply (Brown et al., 1989; Lave & Wenger, 1991). Shared cognition views collaborative learning as a process of building and maintaining shared understandings in authentic learning environments (Roschelle & Teasley, 1995). Clearly, theories of shared and situated cognition are closely related.

The principles of shared cognition guide the examination of collaborative learning processes and NDM and shared cognition are highly compatible. However, what team members share needs to be clearly defined, e.g., task-specific knowledge, task-related knowledge, knowledge of teammates, or attitudes/beliefs. That is, 'shared' in shared cognition needs to be operationalized. For example, does 'shared' mean overlapping, similar, identical, complementary, or distributed? Can the notion be measured and if so how? Developments in computer network technology offer possibilities for investigation of the notion of 'sharedness' beyond the conditions of traditional face-to-face

communication. These important issues guide the design and study of computer-supported collaborative learning and will be discussed in section 2.3.

2.2.2.3 Distributed cognition

Proponents of distributed cognition argue that cognition is distributed among people and tools as opposed to residing in the heads of individual learners (Hutchins, 1995). Cognition is distributed because the knowledge and effort required to solve many problems are often distributed among participants and environments.

There are different views of how cognition is distributed (Salomon, 1993c), such as dynamic interactional (Salomon, 1993b) or cultural-historical view (Cole & Engestrom, 1993). Salomon (1993b) argues that because cognition is rooted in psychological, social and cultural processes, learning is distributed among individuals, via artifacts and shared language. Three themes have emerged concerning this perspective of distributed cognition: (a) the increasingly important role of technology in handling intellectual tasks to ease individual cognitive load, (b) an emphasis of Vygotsky's socio-cultural theory of how externally mediated social interactions explicate certain processes, that are then internalized, and (c) a dissatisfaction with the view that cognition resides entirely in the minds of individuals. These three themes have helped to focus attention on cognition as situation dependent and socially distributed (Salomon, 1993a).

Cognition is also distributed among the various elements of activity systems, e.g., members, the medium culture, the social world, and time if taking a cultural-historical perspective (Cole & Engestrom, 1993). Thus, cognition is not simply a mental quality, it is the product of relationships between mental structures and culturally constituted intellectual tools (Pea, 1993; Sternberg & Preiss, 2005). Cognition is embedded in tools,

modes of presentations, and other artifacts that have been created by offloading heavy cognitive demands. According to Pea (1993), external resources change the nature and function of systems from which such activities emerges. In a similar way, Sternberg and Preiss (2005) proposed that beyond paper-based skills and thought processes, tools including information and communication restructure human thinking. The study of distributed cognition is not limited only to people in systems, it also takes into account tools and technologies and suggests notions that should be applied in the design of CBLEs in order to reduce the cognitive load on humans (Lajoie, 2005; Lajoie, 1993; Lajoie, 2000). Such tools may take the form of external memory systems (Lajoie, Greer, Munsie, Wilkie, Guerrero, & Aleong, 1995), reference sources (Lajoie et al., 1995), communication system (Hutchins & Klausen, 1996), or other technologies used for daily work (Hutchins, 1995).

Cognition in critical settings is typically distributed among members of clinical teams and across physical media such as clinical notes (Xiao, 2005). Knowledge, skills, and actions are distributed in such settings due to the nature and amount of knowledge that needs to be attended to. Physicians work in hierarchical systems where junior residents take care of patients first and seek assistance from senior residents, staff physicians and other specialists when they run into difficulty. Specialization allows doctors at different places in the hierarchy to focus on and attend to their central duties, and thereby think and operate more effectively.

Each of the three perspectives on collaborative learning has a particular value for the investigation of collaboration in specific contexts. For example, situated cognition emphasizes context knowledge and dynamic feedback; shared cognition emphasizes the

building and maintaining of shared understandings in authentic contexts; and distributed cognition emphasizes the distribution of expertise among people, environments, and artifacts.

The discussion of the three perspectives of collaborative learning provides insights on the examination of collaborative problem solving and decision-making. Since medical problem solving and decision-making typically are in collaborative situations, both the collaborative and cognitive nature of such activities must be investigated. Section 2.2.3 will describe how collaborative problem solving activities have been examined from multiple perspectives.

2.2.3 Collaborative Problem Solving

Collaborative problem solving is a form of collaborative learning. The methodology for studying collaborative problem solving is substantially more complex than that for simply examining problem solving, as discussed in section 2.1.1. In collaborative problem solving, interaction (communication and social activity) and cognition are dynamic mutually reinforcing processes that shape and are shaped by each other (Frederiksen, 1999).

Most studies tried to establish relationships between cognition and interaction by focusing on the latter, especially to explore how interaction influences cognition and what aspects of interaction influence cognition. In their study of how high school students used computer simulations to solve velocity and acceleration problems, Teasley and Roschelle (1993) used microanalytic method to identify and describe that interaction as the general form of discourse used to overcome barriers to joint problem solving. These include turn-taking structure that students used to share knowledge and deal with

divergent understandings. Question-asking was also found to influence student problem solving. Hmelo (2002, 2003) found that in student-centered tutor-facilitated problem-based learning (PBL) environment, students formulated many questions and explanations. Hmelo's results also showed that such students had superior problem solving skills. In a study of peer-peer collaboration, King (1999) found that certain types of questions can guide learner cognitive and metacognitive activities in peer-peer problem solving. She identified three types of strategic questions: planning, monitoring, and evaluation and found that students who were trained to ask and answer these types of questions were better problem solvers than untrained students because such trained students activate existing problem-related knowledge, analyze problem components, reconceptualize problems, evaluate alternatives, and access strategies already in knowledge bases. Training can also generate socio-cognitive conflicts and the search for solutions to such conflict. Finally, encouraging students to articulate their reasoning provides them with opportunities for modeling effective cognitive and metacognitive behaviors.

Other studies relate cognition and communicative interaction by focusing on examining cognitive processes during collaborative problem solving. Okada and Simon (1997) found that paired learners outperformed single learners in verifying hypotheses and making justifications. In an in depth qualitative examination, they found collaborative exploratory activities such as making justifications and requesting explanations from others have an important impact on verifying hypotheses.

Although collaborative problem solving studies have examined both cognition and communication, most have focused primarily on one or the other and most have used mainly qualitative methods. Recently, some studies have begun using multiple methods

to correlate the two perspective in order to find out the relationships between particular cognitive and interactive activities (Avouris, Dimitracopoulou, & Komis, 2003; Chiu, 2000; Saab, van Joolingen, & van Hout-Wolters, 2005). Further, as more collaborative problem solving activities are implemented in the online environment with the development of CBLEs, multi-analytical methods will be increasingly needed to examine the correlation between cognition, and communication in computer networked environments.

This section looked at the use of various methodologies to examine different aspects of collaborative problem solving: microanalytic methods (Teasley & Roschelle, 1993), discourse methods (Hmelo-Silver, 2003; King, 1999), task-oriented methods (Avouris et al., 2003), and combined methods (Chiu, 2000; Okada & Simon, 1997; Saab et al., 2005). The lesson is that there is no one adequate analytical model of collaborative problem solving because it is such a complex activity. Consequently, different models are needed to focus on specific aspects of collaborative problem solving. However, given that both social and cognitive processes are involved in collaborative problem solving, a combination of social and cognitive methods, techniques, and perspectives must be applied to research on collaborative learning, especially given recent developments in computer-supported collaborative learning (CSCL).

2.3 Collaborative Learning Tools

As cognitive tools, computers and computer networks offer many features that support learning (Lajoie, 1993; Lajoie, 2000) and as interests in collaborative learning grows such tools are becoming increasing useful. Cognitive tools that support collaborative learning can be called collaborative learning tools and include tools that

support visualization, such as content-specific and content-unspecific tools, tools that support argumentation, such as synchronous or asynchronous tools, and tools that support management, such as mirroring tools, metacognitive tools and advising tools. This section will first describe three CSCL environments that are equipped with some of these tools and then discuss in detail the characteristics of these collaborative learning tools.

2.3.1 Three Well-recognized Collaborative Tools

CSCL tools have been widely used as supplementary approaches in science (Baker, de Vries, Lund, & Quignard, 2001, March; Baker & Lund, 1997; Diehl, 2000; Hoadley & Linn, 2000; Suthers, Connelly, Lesgold, Paolucci, Toth, & Weiner, 2001), math (Baker, Cohen, & Moeller, 1997; Vahey, Enyedy, & Gifford, 2000), and writing (Feltovich, Spiro, & Coulson, 1995; Lingnau, Hoppe, & Mannhaupt, 2003; Neuwirth & Wojahn, 1996). This section will review three theoretically relevant and empirically successful CSCL environments in each area respectively: Belvedere, Probability Inquiry Environment (PIE), and PREP. Table 2.1 summarizes the three CSCL environments with respect to subject domains, pedagogical goals, collaborative learning approaches and technical features.

Table 2.1. Summary of Three CSCL Environments

Collaborative	Belvedere	PIE	PREP
Tools			
Domain	Science	Math	Writing
Goals	Scientific inquiry	Inquiry	Writing skills
Learning	Shared cognition,	Situated learning,	Shared cognition
Approaches	Cognitive apprenticeship,	Shared cognition	
Technical Features			
Visualization	Shared graphics, networked diagram	Shared graphical workplace	Networked link- nodes structure
Argumentation	Face-to-face or online communication	Face-to-face communication	Guided and structured communication
Management	Provide guidance	N/A	N/A

Subject domains and goals

The three CSCL environments deal with science, math, and writing respectively. Belvedere (Suthers, 1998; Suthers, Weiner, Connelly, & Paolucci, 1995) is a shared graphical workplace that supports middle and high school student scientific argumentation skills. PIE is a dynamic simulated learning environment that facilitates middle school student math inquiry skills in elementary probability (Vahey et al., 2000).

And PREP Editor (Neuwirth, Kaufer, Chandhok, & Morris, 2001; Neuwirth & Wojahn, 1996) is a type of word processor that allows writers and reviewers to develop writing skills.

Collaborative learning approaches

All three CSCL environments were designed based on collaborative learning approaches, such as shared cognition, cognitive apprenticeship, or situated learning.

Belvedere integrates both shared cognition and cognitive apprenticeship approaches into its design. It has a shared graphical workplace in which students construct inquiry diagrams which relate data and hypotheses by evidential relations (Figure 2.1). Students can work on the same task in pairs on the same machine or on different machines but with shared workplace in which they can work on each other's argument and then immediately share them with others. Belvedere also provides online help in the form of cognitive apprenticeship. It has an online coach to provide students with suggestions on how to use the software during the five phases of inquiry: exploring, hypothesizing, investigating, evaluating, and reporting. It also scaffolds student inquiry processes by asking them questions.

The design of PIE is informed by situated learning and shared cognition. Students are given probability problems with empirical data in contextualized learning activities. For example, students actively investigate probability outcome spaces by trying to determine whether or not particular games of chance are fair to all participants (Figure 2.2). PIE also has shared a graphical workplace to ensure that all student ideas are presented and examined. Also by showing disagreements in predictions among

collaborations, it externalizes cognitive conflicts which become sources of further collaboration.

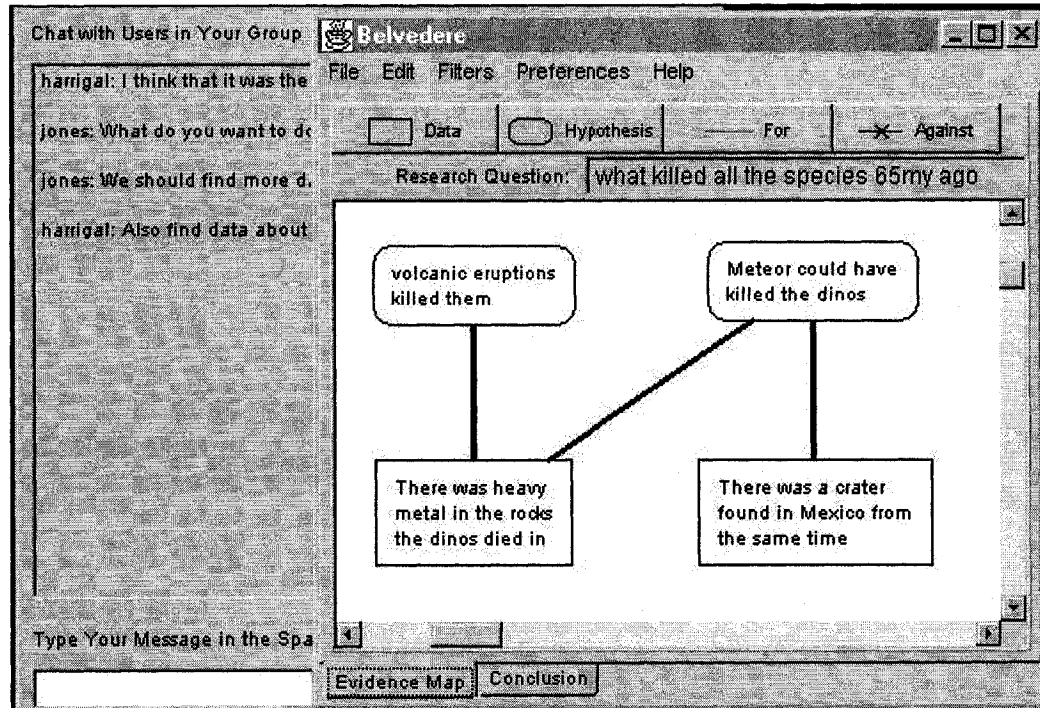


Figure 2.1. Belvedere Inquiry Diagram¹

¹ From "Representations for scaffolding collaborative inquiry on ill-structured problems" by D.Suthers,1998. Paper presented at the conference of *American Educational Research Association*. San Diego. Reprinted with the permission of the author.

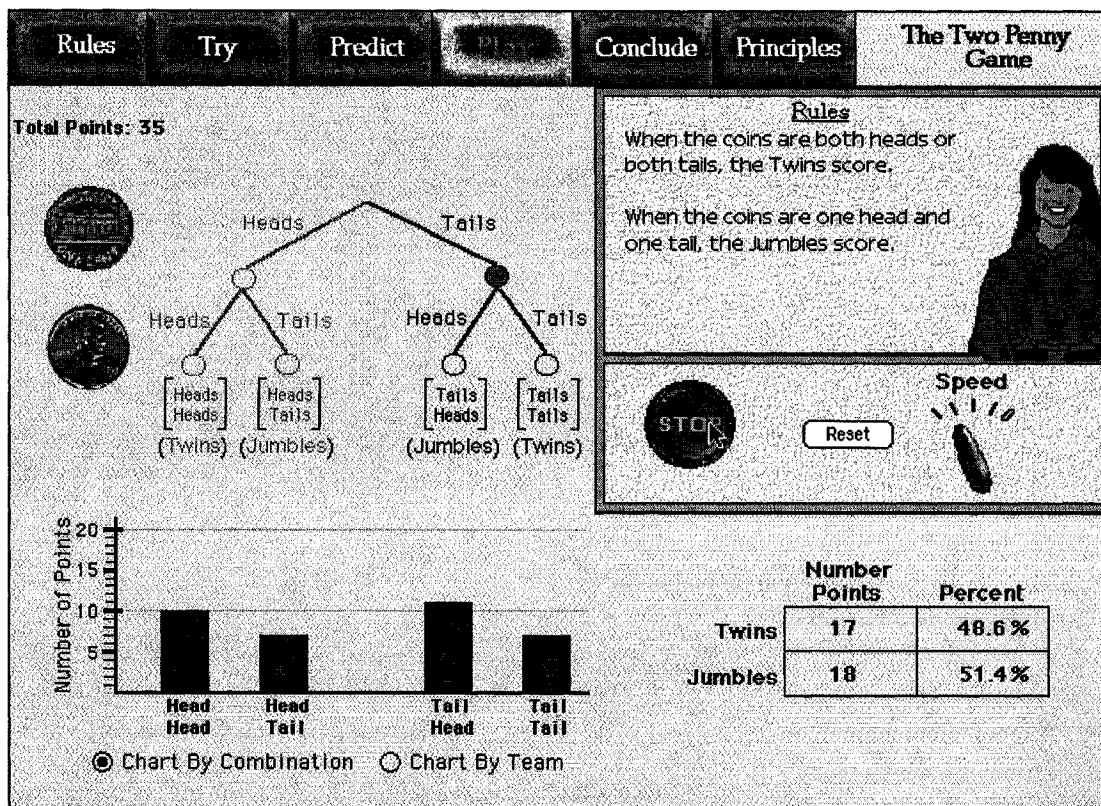


Figure 2.2. PIE Interface²

PREP editor facilitates collaborative writing by providing a shared workstation where students can review each other's drafts, articulate and externalize revised knowledge and communicate information (Figure 2.3).

² From "Learning probability using a collaborative, inquiry-based simulation environment," by P. Vahey, N. Enyedy, & B. Gifford, 2000. *Journal of Interactive Learning Research*, 11(1), p. 62. Copyright 2000 by the Association for the Advancement of Computing in Education. Reprinted with the permission of the author

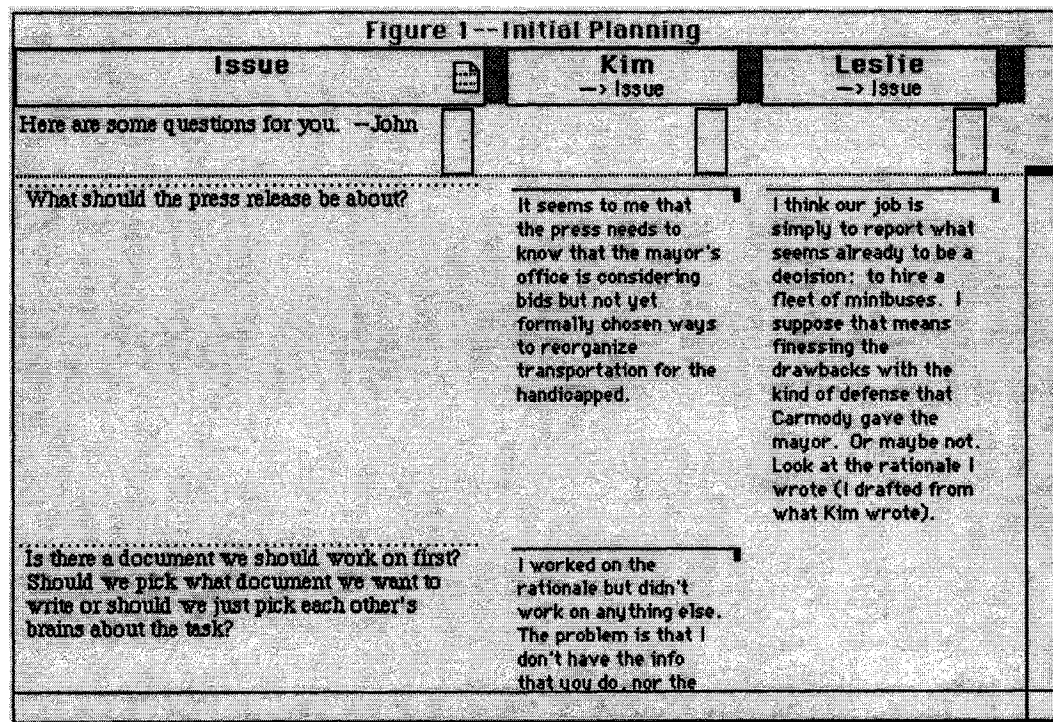


Figure 2.3. PREP Editor Interface³

Technical features

The three CSCL environments provide various technical features to support collaborative learning: visualization representation, collaborative argumentation, and online management.

³ From "Computer support for distributed collaborative writing: A coordination science perspective," by C. M. Neuwirth, D. S. Kaufer, R. Chandhok, & J. H. Morris, 2001, *Coordination theory and collaboration technology*. p. 540. Copyright 2001 by Lawrence Erlbaum Associates. Reprinted with the permission of the author.

Visualization representation: Belvedere uses networked graphics to support the development of student arguments. Students use different graphical languages to express hypothesizing, data-gathering, and information weighing, and by creating different symbol systems to represent logical and rhetorical relationships within arguments. For example, different links are used to represent relationships between such ideas as *for* and *against* (Figure 2.1). Networked graphical computer environments help students to articulate and compare theories and associated arguments, and to alter them in response to new evidence or criticism. Figure 2.1 illustrates how Belvedere helps students solve problems and track ideas by displaying each step graphically.

PIE provides multiple dynamic representations to ensure student ideas are systematically tested. For example, during the Play stage, coins, probability trees, bar charts, and frequency tables are used to provide visual representation of probability outcome in a coin fairness game (Figure 2.2). A probability tree enumerates all the possible outcomes and visually presents the scoring combinations for each team and a dynamic bar chart shows scoring either by combination of coins, or by teams.

PREP Editor focuses on providing visual representations of information and annotations of collaborators' work (Figure 2.3). Visual representations include such features as the shading and spatial relationships among different functions to indicate interconnections among chunks of text. The underlying "node-link architecture" supports collaborative annotation. "Annotation links" are links between columns, e.g., links between source columns and comment columns, which allow users to create annotations rapidly. Visualizations of annotation nodes and links enable students to trace their collaborative work.

Argumentation: Belvedere supports both face-to-face and online argumentation. It has been found that Belvedere's diagramming functions stimulate students to produce more productive critical discussions (Suthers et al., 1995). Students also use text-based 'chat' windows and work in the same place or in difference places, synchronously or asynchronously (Suthers, 2003b).

PIE's particular representation mediates face-to-face interaction. To investigate probability outcome spaces, students go over a six-step inquiry cycle: Rules, Try, Predict, Play, Conclude, and Principles (Figure 2.2). Each step serves as an identifiable stage to support particular kinds of interaction. For example, Play stage features such as coins, probability trees, bar charts, and frequency tables facilitate productive interaction (Enyedy, 2003).

PREP editor support online interactive planning, drafting, and reviewing, which are the key elements of writing (Hayes & Flower, 1980). Collaborative writing involves reviewing each other's drafts, articulating and externalizing revision knowledge and communicating information. In addition, the annotation feature facilitates effective interaction. For example, 'explanation' is used to explain why corrections are made, 'question' is used to view questions asked by learners, and 'comment' is used to view teacher comments.

Management: Belvedere's online coach provides suggestions on demand rather than when students make mistakes (Paolucci, Suthers, & Weiner, 1996). Advice is phrased as suggestions and questions because an automated advisor cannot be assumed to have sufficient information. This coaching strategy displays student weaknesses in the argumentative processes and strengthens student knowledge of scientific inquiry. For

example, if no empirical data is offered in support of a hypothesis, the Coach will highlight the hypothesis and ask whether the student can find a way to support it or show that it predicts or explains the phenomenon under discussion. If only one hypothesis has been stated in the discussion, the Coach will point out that scientists compare alternative explanations, and ask students whether another hypothesis might explain the same data (Suthers, 1999).

This section has described the theoretical and technical features of three CSCL environments. From a theoretical perspective, shared cognition, situated cognition, or cognitive apprenticeship can be integrated into the design of learning activities to support collaborative learning (Hall, Koschmann, & Miyake, 2002). From a technical perspective, tools are needed to facilitate shared visualization, collaborative argumentation, and online management. These features will be described in detail in broader contexts in the section 2.3.2.

2.3.2 Framework of Collaborative Tools

CSCL environments typically employ representation tools (Roschelle & Pea, 1999), such as concept maps, graphics, or diagrams that allow group members to construct, elaborate and augment knowledge. Visual representations have been found to aid individual understanding and problem solving (Larkin & Simon, 1987; Zhang, 1997, 2002) and to serve as mindtools affording multiple knowledge representations for learning (Jonassen & Carr, 2000). Such representations include: (a) semantic organization tools, such as databases and semantic networking; (b) dynamic modeling tools, such as spreadsheets, expert system, systems modeling, microworlds, (c) visualization tools, such as graphics, diagrams, concept maps, and (d) argumentation tools, such as synchronous or

asynchronous communication channels. The last two tools have been widely used in collaborative learning and will be examined in sections 2.3.1.1 and 2.3.1.2. In addition, it has been proposed that CSCL should be equipped with management functions to track and guide collaborative learning activities (Jermann, Soller, & Muehlenbrock, 2001). This feature will be introduced in section 2.3.1.3.

2.3.1.1 Visualization tools

Visualization tools can be categorized as *content-unspecific* and *content-specific* (Fischer, Bruhn, Grasel, & Mandl, 2002). Content-unspecific visualization tools are graphics editors that are not tied to particular knowledge domains (Hron & Friedrich, 2003). Content-unspecific approaches have shown promising effects on collaborative learning in such fields as chemistry, physics, and mathematics (Jonassen, 2000). Examples will be provided later. Most approaches, such as concept mapping or shared whiteboards, are content-unspecific graphic editors. *Content-specific* visualization tools support domain specific processes of collaborative knowledge construction.

Visualization tools have been used in chemistry (Wu, Krajcik, & Soloway, 2001), physics (Pea, Edelson, & Gomez, 1994), and mathematics (Baker et al., 1997). Expressive visualization tools can translate two-dimensional (2D) static chemical graphics into dynamic three-dimensional (3D) special structures. For example, 3D chemistry molecular modeling (eChem) has been found to promote the conceptual understanding of chemical representations by translating 2D structural formulas into 3D models (Wu et al., 2001). Visualization tools can provide graphics, images, colors, and motion to present large quantities of data in a manner that can allow high school science students to observe atmospheric patterns in large data sets (Gomez, Fishman., & Pea,

1998; Pea et al., 1994). In the Collaborative Visualization project (CoVis), visualization features are tightly integrated into collaborative learning activities and generate logs of the whole experimental process. Students can get a copy of the log, put it into a 'Collaboratory Notebook', annotate the log and use it as a tool for reflection and collaboration (Edelson & O'Neill, 1994). Children's mathematical concepts can be developed with the help of symbol representations of mathematical objects/noun type entities for text and simple pictures, spatial relationship, and operator actions (Baker et al., 1997). KidCode (Baker et al., 1997) enables children to manipulate different kinds of symbolic representations, such as text, images, symbols, and graphs and to communicate about these representations with their peers. It has been found that multiple forms of visualization improve mathematical conceptual understanding and foster communication.

Visualization tools have different formats, such as concept mapping, diagrams, or texts and different representations have been found to affect different aspects of learning and interactions (Suthers & Hundhausen, 2001). Students acquire greater concept fluency and flexibility while using *concept mapping* to collaboratively design and produce a multimedia project while they engaged in shared interaction scenario than in distributed and mediated interaction scenarios (Stoyanova & Kommers, 2001). More communicative interaction occurred between learners while using *electronic diagrams* to solve electricity problem (van Boxtel, van der Linden, & Kanselaar, 2000; van Boxtel & Veerman, 2001) because diagrams provide shared views that can help students get an overview of the complex problem solving process. Shared visualization of diagrams can stimulate a continuous focus on thematic content. *Text representations*, such as threaded discussions

and other text representations can facilitate the conceptual understanding of physics concepts (Hoadley & Linn, 2000).

Content-specific visualization tools support both the process and the quality of domain specific collaborative knowledge construction. In terms of processes, these tools induce higher level discourse with more on-task pre-structured visual representations of knowledge and show conflict-oriented consensus building (Fischer et al., 2002). In terms of quality, they foster task-relevant externalizations of abstract concepts (Suthers & Hundhausen, 2001).

Visualization tools are generally integrated with tools to mediate argumentation or monitoring learning. The next two sections will discuss how these tools are used in CSCL environments.

2.3.1.2 Argumentation tools

Argumentation is a key component of collaborative problem solving and knowledge building. It is a complex and variable activity, ranging from negotiation, and justification, to persuasion (Andriessen, Baker, & Suthers, 2003). Computer environments can scaffold the argumentation processes by supporting collaborative elaboration, by providing opportunities for explaining and reflecting, and by helping students keep track of their ideas (Lajoie, Lavigne, Guerrero, & Munsie, 2001). Computer supported argumentation can be represented as computer mediated communication, structured interaction, argument representations, and active guidance of argumentation. These four features are described in detail below.

Argumentation tools can enable communication to occur synchronously or asynchronously. Synchronous communication occurs when learners interact at the same

time either face-to-face or over computers via text, audio, or video files. Synchronous communication format ranges from typed messages to networked, objected-oriented, multi-user, virtual environments for immersing learners in conversation (Jonassen, 2000; Jonassen & Carr, 2000). The immediacy of synchronous interactions has the social advantage of motivating participants to engage in and carry on interpersonal negotiations. Students are allowed to test and refine what they are learning in a community that offers immediate feedback to their thinking and writing processes. Asynchronous communication tools address the issue of temporal separation. They give students time to reflect before responding. Examples of asynchronous argumentation tools are e-mails, threaded discussions, and collaborative notebooks. E-mail was found to facilitate both teacher-students communication (Levin, Haesun, & Riel, 1990) and peer-peer interactions (Baker et al., 1997). Threaded discussions can promote both communities of inquiry and cognitive apprenticeship (Lajoie, Garcia, Berdugo, Marquez, Espíndola, & Nakamura, 2006). The instructor can use discussion forums to scaffold effective student use of communication technology and course content. Collaborative notebooks allow students to co-construct knowledge and to share it visually across time and space (Edelson & O'Neill, 1994; Scardamalia & Bereiter, 1996; Winne, 2006). For example, the Knowledge Forum of the CSILE project is a graphical collaborative knowledge building notebook (Scardamalia & Bereiter, 1996, 1999) on which students post ideas and questions. In addition, students 'build on' to notes, 'reference' others' work, make solicited 'contributions', and 'rise-above' previous notes to create new syntheses, or make 'collections' of related notes. The interactive and collaborative nature of this asynchronous communication allows students to share perspectives, establish

relationships, and seek assistance (Chong, 1998), distinguish alternative views on scientific topics (Hoadley & Linn, 2000), and promote sustained and in-depth discussions (Guzdial & Turns, 2000).

Argumentation tools should structure interactions to improve the orientation of participants with respect to subject matter, reduce off-task talks, support greater coherence in subject matter discussions, and increase focus on topics (Hron et al., 2000). In synchronous communication, structuring is achieved through communication acts (Baker, 2003) or sentence openers (Baker & Lund, 1997; Hirsch, Saeedi, Cornillon, & Litosseliti, 2004). In asynchronous communication, structuring is determined by task-required processes. For example, knowledge construction tasks require posting notes and making comments (Fischer et al., 2002; Scardamalia & Bereiter, 1996). If scaffolding is involved, the discussion framework should have multiple representations that help students express their own opinions and integrate the opinions of others (Hoadley & Linn, 2000).

Argumentation tools should support the construction of an argument representation, i.e. a dynamically created visual representation of argumentation, such as Belvedere (Suthers et al., 2001). Visual representations of arguments can serve as external frames for constructing knowledge and solving problems (Hron & Friedrich, 2003). They can encourage explicit exploration and negotiation, thus improving the effectiveness of knowledge construction. Argumentation representations can shape the arguments' context either epistemologically or heuristically. Both of them are useful for different reasons. If a representation has an epistemological design, argumentation is carried out through less-structured communication forms, such as Emails or non-threaded

discussions. If a representation has a heuristic design, argumentation is carried out through well-structured communications forms, such as threaded discussions (Jermann & Dillenbourg, 2003; Suthers & Hundhausen, 2003) or predefined argumentation structure (Suthers, 1999).

Argumentation tools should help guide argumentation. Individual guidance is very common in intelligent tutoring system (ITS). However, one-on-one guidance is rarely explored in CSCL research and will be discussed in section 2.3.1.3.

There are two major pitfalls in dealing with social interactions in CSCL environments: a) the interaction is taken for granted or b) its social psychological dimensions outside of task contexts are ignored (Kreijns, Kirschner, & Jochems, 2002). Communication exists in both on-task and off-task context and social interactions can directly foster both content and instructional interaction. To encourage collaborative learning, social interaction can be initiated in CSCL environments by tools, i.e. Group Awareness Widget (WAG) – which supports learner group awareness about others in task and non-task contexts (Kreijns et al., 2002).

2.3.1.3. Management tools

In face-to-face student-centered learning environments, instructors provide students with contingent scaffolding. In ITS, students receive adaptive guidance from computer tutors. In CSCL environments, guidance is provided in more complex ways by three management tools: mirroring tools, metacognitive tools, and advising tools (Jermann et al., 2001; Reimann, 2003). Mirroring tools help manage collaboration by tracing and tracking interactions and collaborative performance among group members. Interaction and performance data can be collected and analyzed for further comparison

and guidance. Metacognitive tools require learners to first construct models of interactions and then to compare them to desired states. Advising tools are used to intervene, advise and guide learners after collaboration data has been analyzed.

Mirroring tools

Ideally, managing collaborative learning involves making students and teachers aware of their actions. Mirroring tools collect raw data in log files and display it to participants. The collected information helps participants reflect on (metacognitive) their actions and provide and receive guidance. Information is tracked and collected by means of a structured interface. For example, in HabiPro (Vizcaino, Contreras, Favela, & Prieto, 2000), a collaborative programming learning environment, the pedagogical and social roles of student group performances are tracked and categorized. Pedagogical support is provided by (a) finding mistakes, (b) putting programs in correct order, (c) predicting results, and (d) completing programs. Social performance is categorized as motivation and participation. The computer system stores different group models according to different pedagogical and social patterns based on the information collected from. While groups of students work with HabiPro, the computer analyzes student performance with respect to various pedagogical and social perspectives and tries to classify groups into new patterns. Mirroring tools also collect student information based on structured learning tools. For example, in gStudy project designed by Winne and his colleagues (Winne, 2006), a learning kit collects and traces students note-taking activities with structured learning tools. Students can select note information from given contexts and then classify them into pre-defined categories. In addition to displaying pre-structured

information, mirroring tools can also carry out statistical analyses on collected collaborative information (Chen & Wasson, 2002).

Metacognitive tools

Metacognitive tools are promising because they can model cognitive, motivational, behavioral and contextual aspects of situations in which students can regulate their learning (Lajoie & Azevedo, in press). In a group setting, metacognition also includes reasoning related to the interaction. Thus, in CSCL environments, metacognitive tools should model states of interaction and provide collaborators with visualizations that can be used to analyze their interactions

Metacognitive tools can model complex group interaction variables by displaying student participation statistics and patterns. For example, COTRAS can display the number of messages each student has sent as they solve traffic light tuning problem collaboratively (Jermann, 2004). The system shows students the desired state of interaction as well as the observed interaction and students can use the standard to judge the quality of their interaction and decided whether to take remedial actions. Tools like that have a positive impact on a metacognitive activities by aiding in the construction and maintenance of a shared mental model of the interaction (Soller, Martinez, Jermann, & Muehlenbrock, 2005). Metacognitive tools can also construct effective models of interaction and use them as criteria to provide guidance. EPSILON (Soller & Lesgold, 2003) monitors group communication patterns and problem solving actions in order to identify situations in which students effectively share new knowledge with peers while solving object-oriented design problems. Effective and ineffective knowledge sharing interactions are recorded in an information log of student speech acts (e.g. Request,

Opinion, Suggest, Apologize) and workspace actions (e.g. one student created a new online class). Knowledge sharing episodes are considered effective if one or more students learn newly shared knowledge as shown by pre-post test performance differences. Appropriate guidance is given if ineffective knowledge sharing is detected.

Advice tools

Advice tools are used to guide collaborators by recommending actions for improving their learning and interaction. Since effective collaborative learning includes both learning to collaborate effectively and collaborating effectively to learn, advice tools should address both social collaborative issues and task-oriented issues.

HabiPro (Vizcaino et al., 2000) provides both pedagogical and collaborative guidance based on different group models. With respect to pedagogical advice, if a group chooses a solution without explanation, the system suggests a ‘finding mistakes exercise’ to students by adding clues to help them find mistakes. With respect to collaborative advice, if the system discovers that only one or two students take part in the group activity, it proposes activities to increase group participation, such as activating a rotation turn system so that all students must take part in the work.

Similarly, interaction models are employed in COLER (Constantino-Conzalez & Suthers, 2001), which uses decision trees to coach students to solve database-modeling problems. Entity-Relationship Modeling, also integrates task and social aspects of interaction. COLER provides advice categories for collaboration-oriented and domain-oriented activities. Collaboration-oriented advice includes discussions and participation categories such as ‘ask for justification’ and ‘invite others to participate’. Domain-oriented advice includes feedback, self-regulation, and entity-relationship modeling. For

example, if the system discovers that a student does not participate enough, advice is generated by a decision tree and then selected randomly from each AND/OR leaf of the tree. Thus the student may receive the following advice:

GP: George, participation is a learning opportunity. I suggest you leverage it.

*SC: George, you could share your work with your teammates by adding
CENTER+ITESM relationship to the diagram*

Advice can be provided by a computer agent. Here the agent is defined as a system that exhibits some aspects of intelligent human behavior (Wooldridge & Jennings, 1995). For example, agents often represent different pedagogical roles, such as expert (Johnson, Rickel, & Lester, 2000), tutor (Graesser, Moreno, Marineau, Adcock, Olney, & Person, 2003), mentor (Baylor, 2000; Baylor & Kim, 2003), motivator (Baylor & Kim, 2003), learning companion (Ayala & Yano, 1998; Chan & Baskin, 1990; Dillenbourg & Self, 1992; Goodman, Soller, Linton, & Gaimari, 1998; Uresti, 2000), and troublemaker (Aimeur & Frasson, 1996). The agents assume different roles in the learning system based on different models. It has been found that varying the role of a collaborative agent and adjusting the data in the agent pattern can meet the needs of individual learners and provide collaborative agents for different learning models and different theories.

This section has described various uses of CSCL environments for managing collaboration by means of mirroring, metacognitive, and advising tools. A review of management tools for mirroring, metacognition, and advising reveals that these features are organized into feedback cycles in the collaborative problem solving. Mirroring tools trace, collect, store, and model student interactions, metacognitive tools display and compared desired states with the current states allowing students the freedom to take the remedial actions. Advising tools allow students to propose remedial actions based on the

results of the mirroring and metacognitive tools which can lead to a new cycle of collaborative problem solving.

In summary, collaborative tools can facilitate learning in a number of ways. Visualization tools can be either content-specific or content-unspecific and can use various formats: graphics, diagrams, and concept maps. Both content-specific and content-unspecific visualization tools are useful in different ways: content-specific tools facilitate both the process and quality of collaborative knowledge while content-unspecific tools mainly facilitate the process of collaboration. Argumentation tools may be communicative, structured, representative, and guided. Management tools can facilitate mirroring, metacognition, and advising. An ideal CSCL can be achieved through the implementation of these tools. However, there are trade-offs. For instance, it has been found that the more specific a visualization tool is, the more difficult and time-consuming it is to learn to use (Suthers, Toth, & Weiner, 1997). Furthermore, the more complex an argument is, the greater its cognitive load (van Bruggen, Kirschner, & Jochems, 2002). Thus, when implementing collaborative tools in CSCL environments, it is important be aware of trade-offs between specificity and generality, complexity and simplicity, and autonomy and dependency (Dimitracopoulou, 2005). For a summary of the collaborative tools, see Figure 2.5.

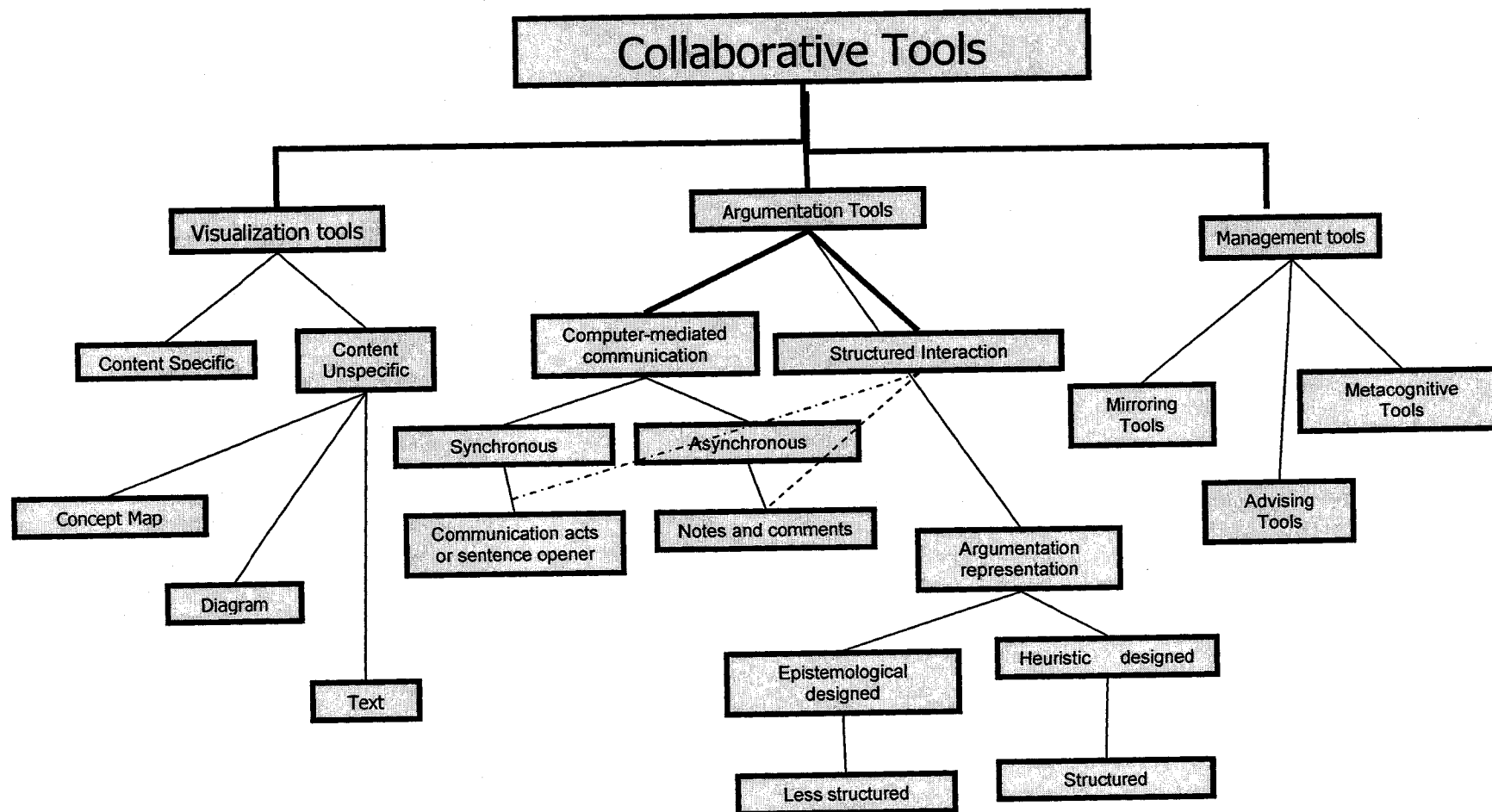


Figure 2.4. Framework of collaborative tools

2.4 Summary

The literature review examined studies in the areas of medical problem solving and decision-making and discussed methodologies they used in order to analyze collaborative decision-making in medical settings. Given the nature of medical problem solving and decision-making in a collaborative context, a review of the collaborative nature of learning was provided as well as computer tools that support collaboration.

This is a study of NDM in which medical students practice patient management skills in simulated medical emergencies, called the “deteriorating patient”. Since this study focuses on “real-life” medical emergency simulations, its theoretical frameworks are different from those of classical problem solving. Instead of focusing on expert knowledge and reasoning for diagnostic tasks, it focuses on decision-making activities for complex management tasks. In addition, previous literature has been focusing on the cognitive processes of problem solving and decision-making, such as diagnostic reasoning, knowledge structure, and decision-making actions. Its collaborative processes and the relationship to cognitive processes have been less fully investigated. This study will examine all the above mentioned issues.

In addition, this study used networked computers to provide shared visualization, representation, and argumentation tools to help students communicate more effectively and thus to construct shared understandings and joint problem space. Because computer technology can be used to promote collaborative problem solving and decision-making, a CSCL environment was designed to allow small groups of students collaborate in solving simulated medical emergencies. Working in small groups can intensify student involvement in the learning activity (see section 3.2.1) by promoting face-to-face or

online communication which in turn facilitated the distribution and construction of shared understandings

Two conditions were introduced. Students in the experimental group (EG) condition worked in small groups using computer-based interactive whiteboard that was designed with visualization and argumentation features. Students in the control group (CG) condition worked in small groups using a traditional whiteboard located at the front of the class. It was hypothesized that interactive whiteboards would enhance student communication and decision-making activities, leading EG students to exhibit more effective collaborative problem solving. Qualitative analysis will determine the relationships between the communicative, decision-making, and technology supported argumentation activities.

This study differs from many studies on medical cognition in three ways: (a) it focuses on naturalistic decision making/problem solving in simulated real world settings as opposed to formalized laboratory-based settings, (b) it focuses on collaborative as opposed to individual learning, and (c) it focuses on diagnosis, monitoring and managing tasks as opposed to only diagnostic tasks. Each of these research perspectives called for different methods and an expanded theoretical framework.

Chapter 3: Methodology

This chapter includes six sections. Section 3.1 introduces the background of subjects of this study, section 3.2 gives a detailed description of the learning activity that was examined, section 3.3 describes the experimental design, section 3.4 introduces the cognitive framework of the decision-making activity which serves as the basis for analysis, section 3.5 introduces the equipment and software used in the experiment, and section 3.6 demonstrates the methods of data analysis

3.1 Subjects

Two groups of seven third-year medical students doing their two-month rotation in the Department of Internal Medicine in a large teaching hospital were recruited for this study. Each group attended two teaching sessions. The first was given at the beginning of their rotation and the second was given at the end of their rotation. In both sessions the students worked in small groups to discuss and solve a learning activity called the ‘deteriorating patient’ designed by Dr. Jeffrey Wiseman (personal communication, November 24, 2005). Participants who were new to clinical practice were selected since they were new to the content and to the process of working in teams. An experienced instructor was selected who was able to adapt his teaching to include a collaborative problem solving activity.

3.2 Description of Learning Activity

The design of this study is based on a learning activity called the ‘deteriorating patient’ which is given to third year medical students at the beginning and end of their internal medicine rotation. To understand the characteristics, rationale, and importance of

this study, it is necessary to understand the features of this learning activity. In this section, first the traditional ‘deteriorating patient’ learning activity will be introduced (section 3.2.1). Next new features that were designed for this thesis for both the experimental and control groups will be discussed (section 3.2.2).

3.2.1 Traditional Learning Activity

Participants in the ‘deteriorating patient’ learning activity participate in a medical emergency role play where they must stabilize a deteriorating patient whose symptoms and signs of disease grow increasingly life threatening as the activity progresses.

The ‘deteriorating patient’ activity seeks to simulate actual medical emergencies that medical students will encounter in ordinary hospitals, such as in the Emergency Room (ER). Participants are placed in situations where they must make decisions quickly based on the patient’s rapidly deteriorating medical condition. In doing so the instructor seeks to induce some of the stress that they will encounter in real medical emergencies. Each teaching session is an hour long and is divided into three stages: explaining the rules, conducting the activity, and debriefing. For better understanding the “deteriorating patient” activity, please see Figure 3.1 for the procedures.

Stage 1 the rules (5 minutes): The teacher explains how the activity works and how to play the roles. For instance, the teacher specified that when students find they cannot solve a problem, they can call for help from the senior medical staff played by other students.

Stage 2 the activity (20-25 minutes): The students solve the problem by playing different roles in turn, such as medical student, junior resident, senior resident, or ICU specialist.

Stage 3 the debriefing (20-30 minutes): The teacher summarizes the case, has students reflect on their actions and suggests ways of improving their performance. Students use their biomedical knowledge to explain the medical emergency they dealt with in stage 2.

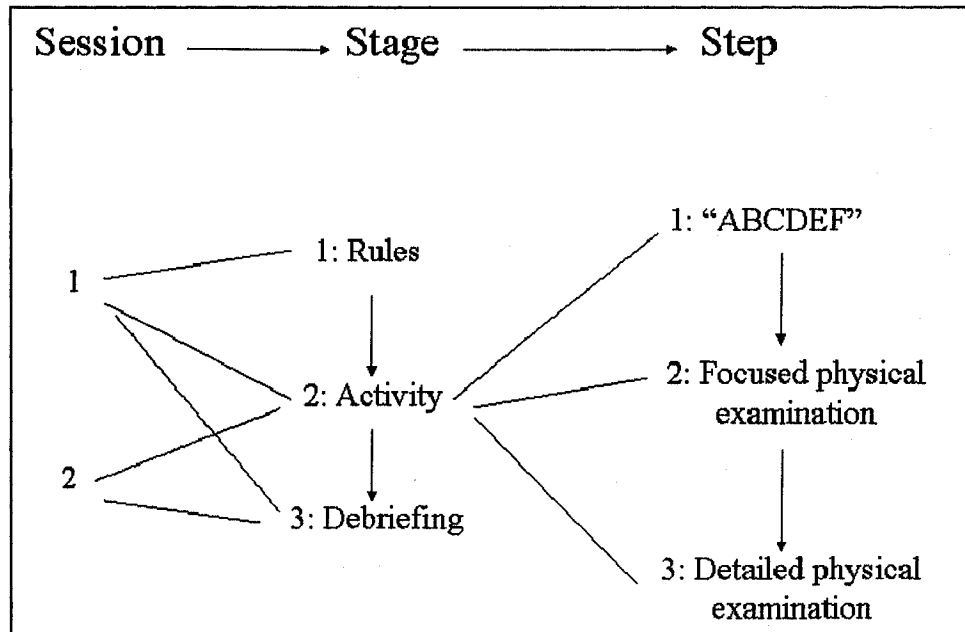


Figure 3.1. Procedures in "deteriorating patient"

In traditional teaching scenarios, there are normally six to seven students who participate in the 'deteriorating patient' interaction activities. Various students play the roles of medical student, junior resident and senior resident while the teacher plays the roles of the deteriorating patient and the duty nurse.

Rules In teaching session 1, the teacher explains rules:

So the rules again are as follows: If you do the right thing, for your patient in a timely fashion, your patient will remain stable or get better. If you do something else or if you do the wrong thing or take too long to get the needed treatment to

your patient, your patient will start deteriorating. The deterioration will be made specific to what you do or are not doing to that patient. If you pick up that deterioration and do something about it, or do the right thing about it, the deterioration will correct by itself. If you keep ignoring the deterioration, the patient will continue to deteriorate. Until you figure it out.

When playing a role each student must work alone and other students are not allowed to offer help. The teacher explained *'I am trying to reproduce the cold frightening feeling that you get when you're alone with the patient. That's the way emergency medicine is. It's never like in the textbook'.*

Next, the teacher presents the case and asks for a volunteer to start solving the problem. When this student runs into difficulty, the teacher tells him to call the junior resident which is played by another student volunteer. When the junior resident reaches an impasse s/he calls the senior resident which is played by a third student volunteer. In this way the activity simulates the operation of a real medical emergency. The teacher plays two roles, the deteriorating patient and the duty nurse. As the deteriorating patient, the teacher acts out rather dramatically the patient's fluctuating physical conditions. As duty nurse he constantly updates patient's fluctuating vital signs and symptoms. Students ask the nurse questions about the patient and based on his answers determine what to do next. The nurse carries out their orders, reports results and delivers updates on the current state of patient's vital signs and symptoms.

The patient acts out his changing vital signs and symptoms based on what the student does or does not do. For example, when a student failed to correct the patient's low blood sugar, the patient slipped from animated confusion into unconsciousness. This

information is presented in a structured chart by the teacher on the whiteboard (Figure 3.2). In this way the teacher, nurse, and patient attempt to recreate some of the stress and cognitive challenges that students will soon face during their emergency medicine rotation. The teacher also tries to focus their attention on emergent issues so as to help students develop situation awareness.

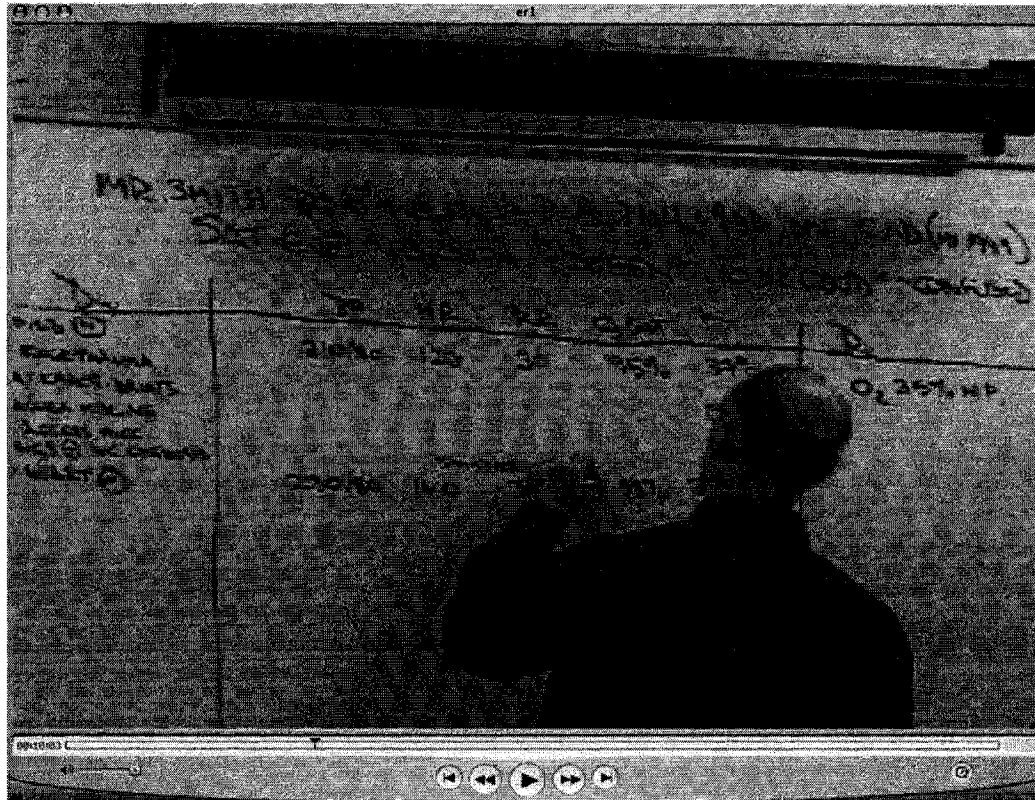


Figure 3.2. The teacher is updating patient's vital signs and mental states.

The 'deteriorating patient' begins with a medical student asking the nurse questions about the patient's medical situation, such as vital signs, breathing, circulation and other important factors in emergency medicine. On the one hand, student questioning is guided by an 'ABCDEF' emergency algorithm where A stands for Airways, B for Breathing, C for Circulation, Central Nervous System and Cervical Spine, D for Drugs, E for Environment and Endo-metabolism and F for Fever. On the other hand, student

questioning is guided by feedback from the duty nurse's reports on the patient's vital sign status, requested lab results, and the patient's physical appearance. Students must constantly monitor and interpret the patient's status and search for information within a highly dynamic problem space. Students seek information about the patient in order to manage and stabilize his or her dynamically evolving condition.

Students sometimes interpret the patient's history, e.g., "The patient has a history of diabetes" or the patient's continuously changing situation, e.g., "His platelets are sky high", indicating their awareness or concerns about the patient. Students also interpret reported results, e.g., "Probably hypo-perfusing his kidneys", and management actions or plans, e.g., "I would say keep it running because he responded to a bolus". They also justify the searching for information, e.g., "I would listen to the heart just to see if there is any, maybe, sign of heart failure", or interpret diagnosis, e.g., "What I am afraid of right now is, first, infection, if there is bacteria, if the antibiotics are not working?" Characterizing and interpreting what students say in these dynamic decision-making scenarios is essential for making sense of their verbal protocols so as to understand the cognitive processes that they express verbally.

During the debriefing stage the teacher presents a three-step framework for dealing with medical emergencies and then replays the case in order to demonstrate how to apply the 'ABCDEF' emergency algorithm efficiently and correctly (Figure 3.3). The three-step framework and 'ABCDEF' algorithm for approaching the 'deteriorating patient' learning activity is developed using cognitive task analysis methods to identify the domain and pedagogical knowledge for this task. The author's analysis was based on

field notes of a series of clinical teaching sessions of the audio and video data. In order to deal with medical emergencies, students follow a three-step framework:

Step 1: the physician does an initial 2-minute six-step “ABCDEF” examination.

Step 2: the physician simultaneously carries out a focused physical exam for diagnostic information, treats immediate symptoms, and monitors the patient.

Step 3: If the patient is stable after Steps 1 and 2 the physician takes the patient’s history, does a detailed physical exam and sending out for lab tests.

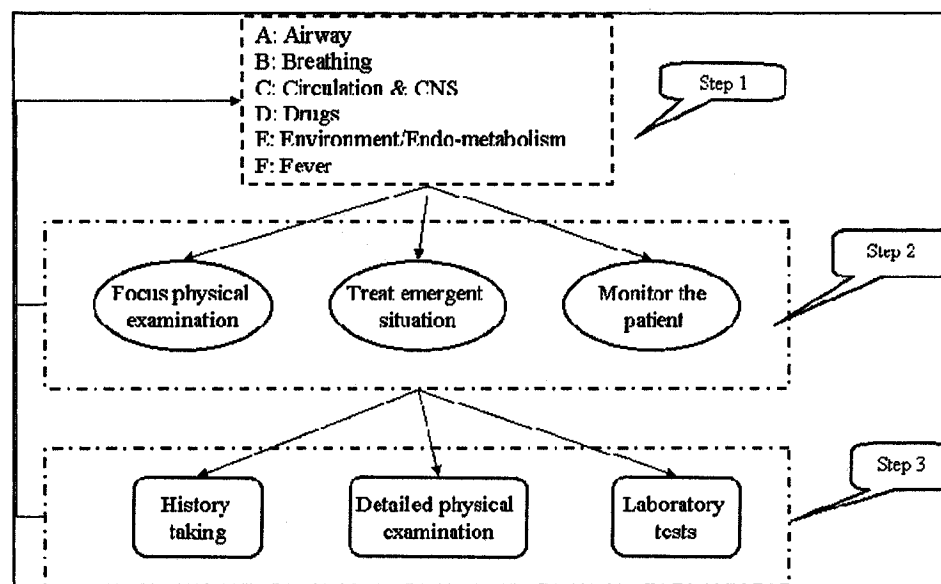


Figure 3.3. Three-step framework for approaching medical emergencies

Teaching Session 1 and 2 are identical except that session 2 omits Stage 1 the rules.

Time limitations dictate that only about half of the six to seven students in each group had a chance to participate in role-play decision making during each session. Students who do not participate observe and it is difficult to determine what, if anything, they have learned. In addition, during the traditional teaching scenario students have no

access to the 'ABCDEF' algorithm until the debrief stage of the teaching activity. This study introduced a number of new features into the 'deteriorating patient' activity in order to build on the theoretical rationale for collaborative learning in naturalistic decision making situations to allow all students to participate and collaborate in Stage 2.

3.2.2 Features Added in the Current Study

1. Students in the experimental and control groups were divided into three groups: two groups of two and one group of three. Each group took turns interacting with the teacher so that all the students had a chance at solving the problem.
2. To investigate the cognitive processes of observers during Stage 2 and to facilitate collaboration, observers were told to use the interactive whiteboard (IW) to type in annotations about the ongoing decision-making activities of role-playing students and to share them with others.

This study focuses on Stages 2 and 3 of session 1 and 2. Stage 2 consists of collaborative interaction and problem solving. Stage 3 involves analyzing and confirming the findings of stage 2.

The similarities and differences between the traditional teaching activity, the control group, and experimental groups are summarized in table 3.1.

Table 3.1. Summaries of Teaching Activities and analysis in Traditional, Control, and Experimental Group.

Group	No. of students	Whiteboard	Activity	Procedure	Observers	Data	Analysis
Traditional teaching activity	6-7	Traditional	3-4 students take turns solving problems	2 teaching sessions	Observing	N/A	N/A
EG	7 (3 subgroups)	Interactive	All students in 3 subgroups take turns solving problem	2 teaching sessions & Post-test interview	Making annotation on the laptop computer	Classroom discourse, computer records, & post-test interview	Loglinear, ANOVA, Microanalytic
CG	7 (3 subgroups)	Traditional	All students in 3 subgroups take turns solving problems	2 teaching sessions & Post-test interview	Observing	Classroom discourse & post-test interview	Loglinear, ANOVA, Microanalytic

3.3 Research Design

Two groups of seven students were randomly recruited from the class. One group served as the control group, the other as the experimental group. The seven control group students were organized randomly into two pairs and one group of three in order to participate in solving a deteriorating patient problem using traditional whiteboards in the two teaching sessions. The seven experimental group students were also organized randomly into two pairs and one group of three in order to participate in solving a 'deteriorating patient' problem using interactive whiteboards in the two teaching sessions. A post-test in the form of semi-structured interview is given to each participant in both groups after presenting them with a similar clinical case to solve after the two teaching sessions.

3.3.1 Classroom Activity

The decision-making activity in the current study is similar to the one offered in the traditional teaching course. Some features have been added to the control or the experimental groups in order to answer the research questions introduced in Section 3.2.2. A detailed description follows for each group.

Control group Participants were grouped into 3 subgroups: two groups of two and one group of three, for teaching sessions one and two. Individuals in the three sub-groups work together to solve the deteriorating patient problem (Figure 3.4).

1. *Preparation.* After being presented with a case, each sub-group discusses it and comes up with questions to ask the duty-nurse to collect additional patient information in order to formulate plans and actions for stabilizing the patient's deteriorating condition.

2. *Decision-making.* Sub-group 1 as the on-call student collects patient information by questioning the nurse. Group members may take turns asking questions or one student may predominate. Students have brief discussions when there are disagreements. Sub-group 2, as the junior resident, takes over when sub-group 1, as the on-call student, gets stuck which is indicated implicitly by long pauses or explicitly by a request for help. Sub-group 2 now has several minutes to discuss the case in order to come up with questions for the nurse. Similarly when sub-group 2 gets stuck they are replaced by sub-group 3, who as senior resident, follows the same procedure.

Experimental group The experimental group follows the same procedure as the control group except that its participants use interactive whiteboards in addition to a traditional whiteboard. Thus, each of the three sub-groups shares a laptop computer on which they are able to observe whatever the teacher writes on the traditional whiteboard. They are able to add their own comments to the patient chart via a special column. These comments are visible to the other sub-groups via their own laptops. Students were also able to refer to the “ABCDEF” emergency algorithm via a dropdown menu (Figure 3.4).

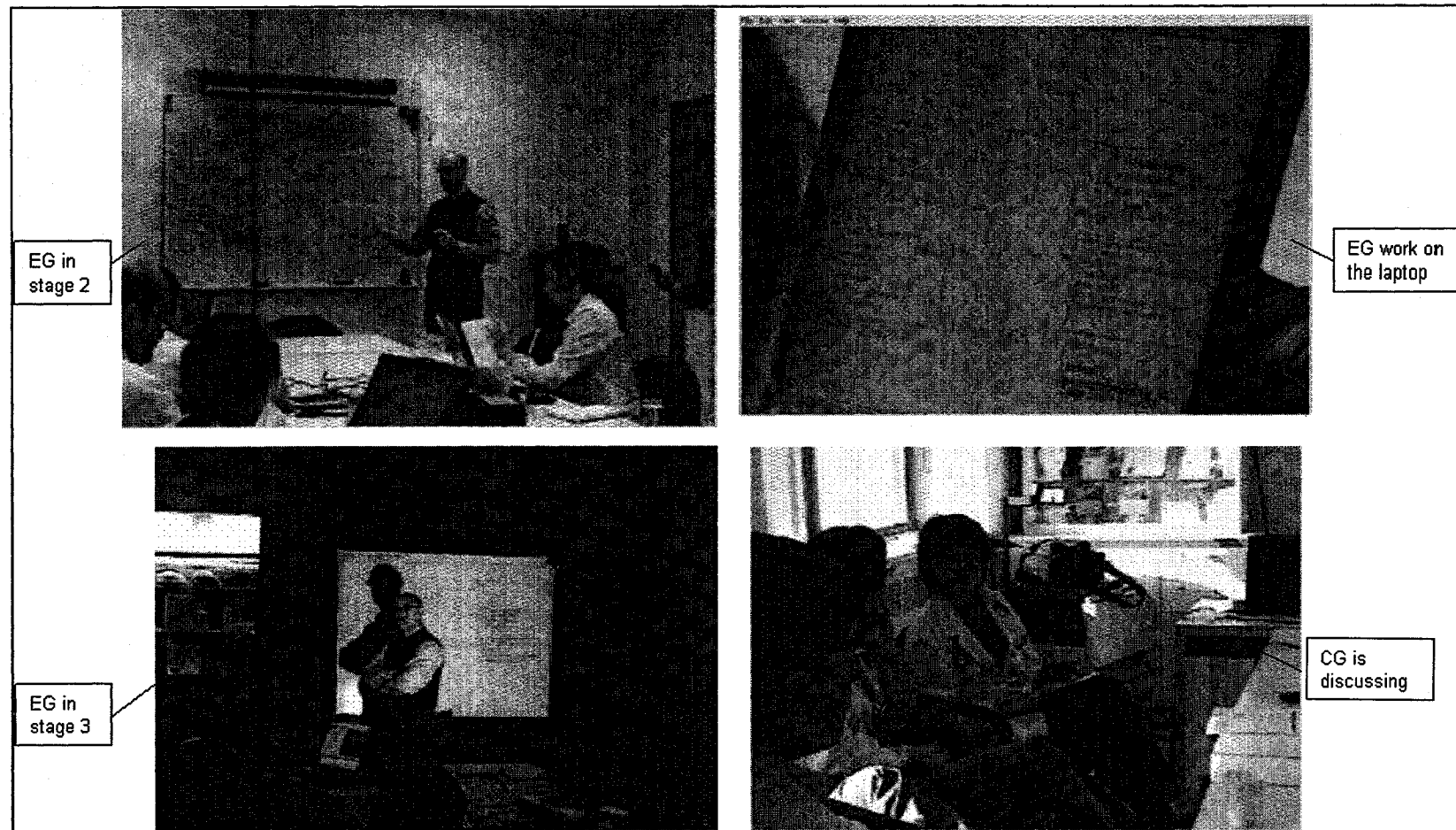


Figure 3.4. Snapshots of experimental and control groups.

3.3.2 Post Test

The post test is a semi-structured interview based on a similar clinical case. Students are presented with a clinical case in video format that was taken from one of the previous clinical teaching sessions. The 10-minute video clip shows one student partially solving the deteriorating patient problem. Participants in this study are asked to say what they would have done if they had been the student in the video: (a) What further medical information would you ask for, (b) What further procedures would you take, (c) What kind of problems does the patient have, (d) Identify the strengths and weaknesses the student as physician makes and why, (e) Predict what the results would be after your actions and the biomedical mechanism of the patient's problem. See Appendix 2 for interview instructions, and Appendix 3 for the transcripts of the clinical case.

3.4 Cognitive Framework of Collaborative Decision-Making Processes

A cognitive framework for decision-making was identified and corroborated by interviews with the teacher who has expertise both in the medical and educational domains. See Appendix 5 for the teacher's cognitive task analysis for this activity.

In the 'deteriorating patient' learning activity, students worked collaboratively to *plan* what patient information to collect and what management procedures to use. Based on brief discussions, they arrived at a consensus and began *collecting patient data* and *managing the patient* based on dynamic feedback about the patient's situation. Students *interpret* results or the situation so as to inform each other or the teacher in order to build a shared understanding of the 'deteriorating patient' problems. Figure 3.5 shows the procedures and relations among them.

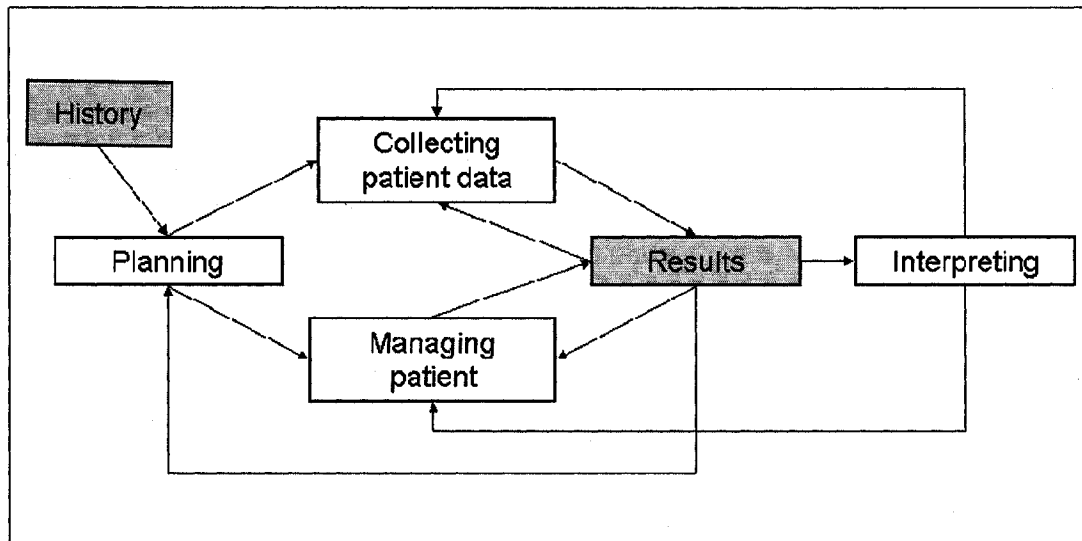


Figure 3.5. Procedures in collaborative decision-making

3.5 Equipment and Software

3.5.1 Interactive Whiteboard Technology

This study used an eBeam™ System 3 Wireless whiteboard with Bluetooth technology. An eBeam receiver is connected via Bluetooth to a computer acting as a server which in turn was connected to a D-Link wireless router enabling three wireless laptops to operate on a local network. Each of the three experimental sub-groups had a laptop which they use to communicate with the other sub-groups via eBeam software. The interactive whiteboard electronically captures notes and images that are written on the traditional whiteboard in real time into the eBeam Software 'Meeting application', and can simultaneously appear on the three sub-group laptops. The server is also connected to a projector via "projection mode," in order to replay the decision-making processes during the Debriefing stage.

Collaborative learning tools were designed and integrated into the interactive whiteboard to support collaborative decision-making in medicine. The tools support shared visualization and collaborative argumentation.

3.5.1.1 Shared visualization tools

Shared visualization tools facilitate collaborative decision making and problem solving by enabling users to construct shared problem spaces. Interactive whiteboards can display in real time not only the representations of the actions of individual role-playing students, but also those of the observers. Shared visualization tools have the following features:

Content specific diagrams Whiteboard diagrams represent what happens in scenarios by displaying content specific information (see figure 3.6). Patient's information is categorized as brief history, vital signs, prescriptions, and decisions. The structure is similar to the patient's chart in the hospital. Brief history refers to the chief complaint and the major reason why the patient needs immediate attention. Vital signs refer to the patient's heart rate, blood pressure, temperature, respiratory rate and oxygen saturation. Decisions refer to the kinds of information students (on-call students, junior residents and senior residents) want to get about the patient and the examination they run, e.g. 'check airway'. Prescription refers to the medication or management given to the patient, e.g., 'put oxygen, 50%, on mask'. Some changes are made in order to make the change of problem space obvious so that students could recognize the pattern of the problem. For example, patient vital signs are put in the middle to highlight the deteriorating situation of the patient. Decisions and prescriptions are marked down

parallel to the changing vital signs to demonstrate the connection of these three kinds of information.

Assessment and meta-cognition The “replay” function of the interactive whiteboard allows the teacher to assess decision-making processes dynamically across different groups or within the same group across different times. It also allows students to reflect on their plans and actions by reviewing their own decision-making processes.

3.5.1.2 Collaborative argumentation tools

Collaborative argumentation tools allow observing students to play an active role by annotating, commenting on and suggesting alternatives to decisions of role playing on-call students. These tools allow observers to participate and to scaffold collaborative decision making by promoting the discussion of various proposed actions and plans. Students are encouraged to give all kinds of comments, either clinical suggestions, such as ‘listen to the lungs’ or biomedical interpretation, such as ‘relevance of prednisone’. It is hoped that in so doing the tools can help learners construct connections between biomedical and clinical knowledge which will further enhance the ability of students to acquire higher cognitive and meta-cognitive skills.

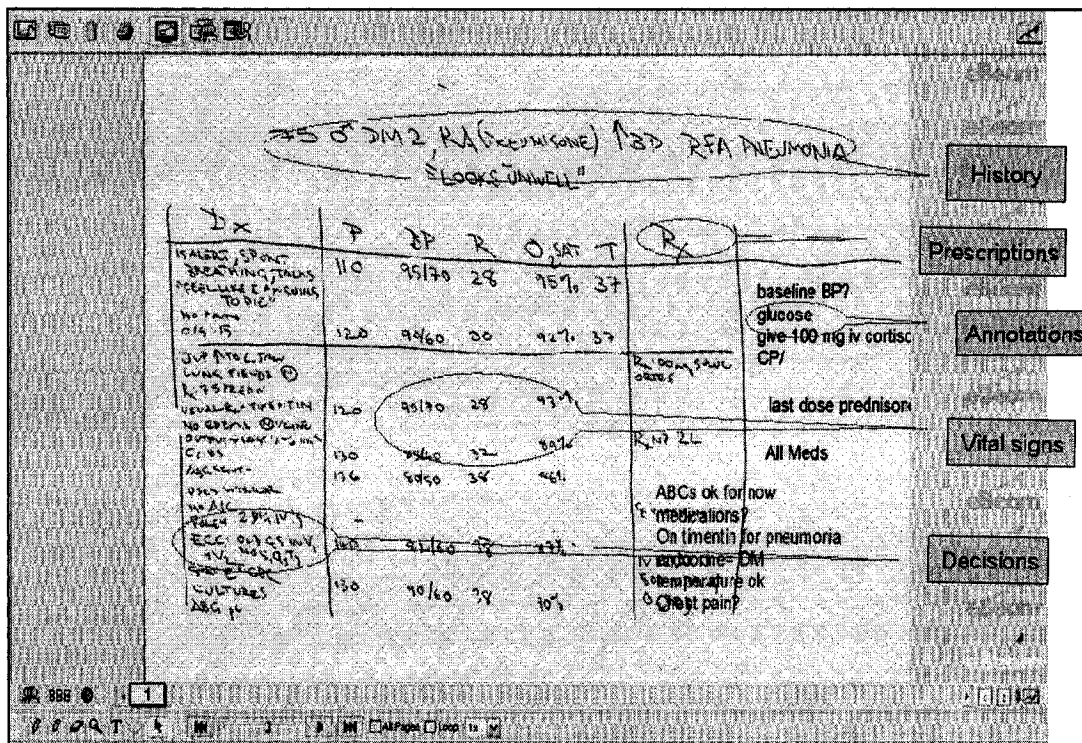


Figure 3.6. Screenshot of eBeam whiteboard

3.5.2 Dropdown Menu

In order to allow students to refer to the 'ABCDE' emergency algorithm while solving a deteriorating patient problems, special software was designed to place the algorithm in an easy-to-read drop-down menu for use during the deteriorating patient learning session (Figure 3.7). In this study, the dropdown menu was used as a reference tool rather than a decision-support device. A detailed and comprehensive text-based emergency algorithm, which was developed by the instructor has been examined and approved by other doctors of Internal Medicine in this setting (See Appendix 5). The algorithm was translated into an easy-to-refer dropdown menu that can be shared by all group members. The electronic algorithm was produced by the author and the instructor. On the first level were six categories: Airway, Breathing, Circulation/CN/Cervical Spine,

Drugs and Toxins, Endocrine/Metabolic, and Fever. Under each of these six categories was a second level menu that provided concise easy-to-follow information about each item. For example, under Circulation were: (a) HR & ECG rhythm, (b) All arterial & aortic pulses palpated, (c) BP pulses paradoxus, (d) JVP, and (c) Urine output. Items in each level category are ordered according to the flow of the algorithm which is specified as 'if, then' conditions.

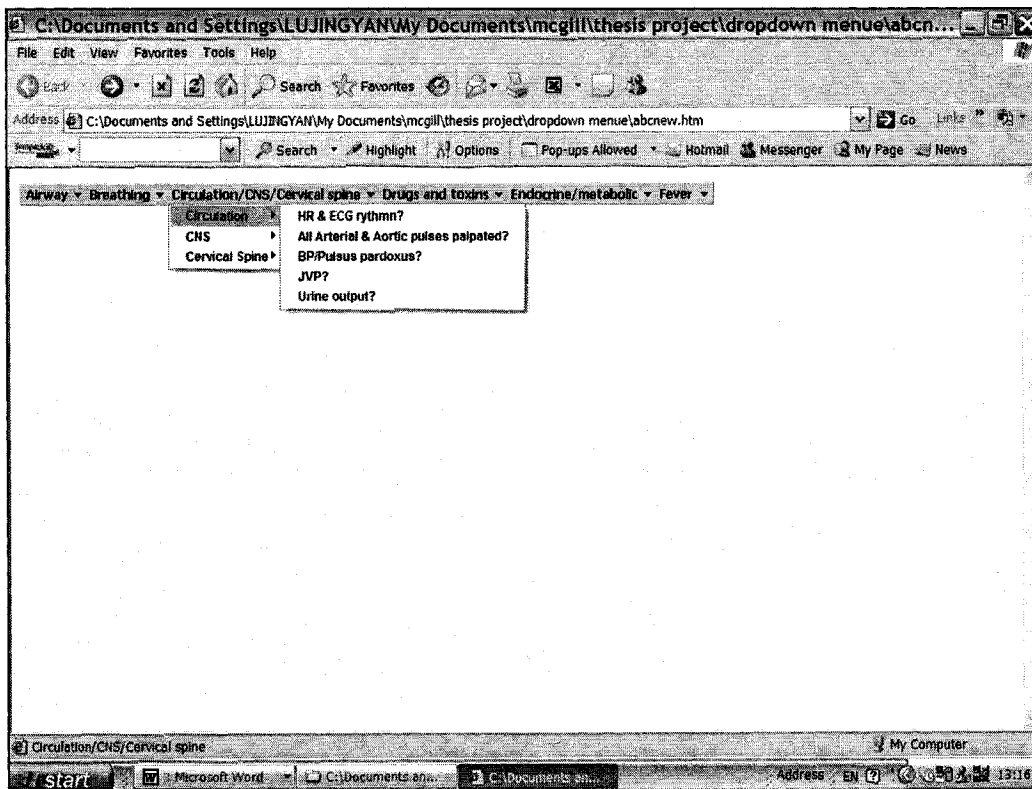


Figure 3.7. Screen shot of dropdown menu.

3.6 Data Analysis

Three kinds of data were collected: (a) collaborative decision-making discourse, (b) computer records of whiteboard annotations and dropdown menu-using behavior documenting students' understanding of the "ABCDEF" algorithm, and (c) post-class semi-structured problem-solving interviews. The sequence of analysis was both top-down

and bottom-up. On the one hand, coding was guided top-down or was theory-driven by literature on problem solving (Chi & Glaser, 1985), decision-making (Lajoie et al., 1998) and collaborative discourse (Kumpulainen & Kaartinen, 2003). And on the other hand, coding was determined through bottom-up interaction with the data (Hogan, Nastasi, & Pressley, 1999). Results from top down method can provide support to the theory or alternatively call it into question. Bottom up method can gradually refine coding schema until it is fully developed.

3.6.1 Records of Classroom Discourse and Decision-making Activities

Audio and video records of student collaborative decision-making were collected. The discourse of each sub-group was audio taped during Teaching Sessions 1 and 2. Given that research questions 1 and 2 dealt with whether and how control and experimental groups differed in their decision-making and communicative activities student verbal protocols were collected, transcribed and coded for these purposes.

3.6.1.1 Decision-making activities

Decision making activities (DMA) were coded in order to identify how collaborating students arrived at decisions: (a) Do the DMA of the experimental group (EG) differ from those of the control groups (CG)? (b) Do the DMA in Teaching Session 1 differ from those in Teaching Session 2? and (c) Do the DMA of the control and experimental sub-groups differ?

The coding schema was developed in a top-down fashion in so far as its categories were based on categories discussed in the literature on solving ill-structured problems and on NDM. The coding schema was developed in a bottom-up fashion in so far as its categories emerged from an analysis of student protocols. A significant feature

of NDM is that the problems dealt with are ill-structured. Ill-structured problems have the following characteristics: (a) the problem statement is not clear, (b) the information to solve the problem is not always contained in the problem statement (Chi & Glaser, 1985), (c) the goals are vague or unclear (Sinnott, 1989), and (d) the problems often lack a clear path to solution (Pretz, Naples, & Sternberg, 2003). In addition, problem representation skills, justification skills, and monitoring and evaluation skills are primary characteristics of ill-structured problem solving (Voss & Post, 1988). Problems having several potential solutions are frequently dealt with by satisficing, rather than maximizing strategies (Sinnott, 1989). This strategy is similar to the findings in decision-making literature.

Decision making in emergency medical situations is often stressful, urgent and oriented to stabilizing patients whilst diagnosing them. Thus, making an ultimate diagnosis is not the only goal of the 'deteriorating patient' learning activity. However, since students must solve problems in face-to-face collaborative situations they occasionally must explain their decisions or make preliminary judgments about a case. They must interpret the problem state, such as the patient's medical history, or provide each other and the instructor with the necessary information in order to deal with the problem at hand.

The unit of coding is the meaningful unit of their verbal protocol (Chi, 1997). It can be a word, a sentence, or a paragraph. Based on the above characteristics, the study examines the dimensions listed in table 3.2.

Table 3.2. Decision-making Activity Coding Categories

DMA	Definitions	Examples
1. Planning	Students formulate plans for collecting patient data and for managing patient condition.	“We should ask the nurse for the vital signs and at the meantime go to see the patient ourselves”
2. Collecting Data	Students collect patient data, i.e., physical condition, laboratory tests, treatment status.	“We will be looking for air input first” “Does the patient have IV or a foley?”
3. Managing	Students manage patient’s condition.	“So I would continue with the IV”
4. Interpreting	Students interpret patient’s condition based on collected data and management interventions to construct shared understandings.	“He has the history of diabetes.” “...because his blood pressure has been getting lower and lower”

3.6.1.2 Communicative activities

Communicative activities (CA) were coded in order to identify the kinds of activities students used to communicate during the ‘deteriorating patient’ activity: (a) Do CG and EG communicate differently? (b) do the CA of Teaching Session 1 differ from those of Teaching Session 2? (c) do the CA of control and experimental sub-groups differ?

CA were identified and coded in order to gain a better understanding of the relationship between collaborative decision making and communication. The unit of analysis could be any meaningful unit of verbal interaction. It can be a word, a sentence, or a paragraph.

The purpose of the CA coding is to characterize how students express and share their understanding of the deteriorating patient's situation, how they negotiate plans and the actions by which they will solve the patient's medical emergency. CA coding was developed top-down in so far as the categories were used with success in previous studies of computer-mediated collaboration (Saab et al., 2005). Since the 'deteriorating patient' activity is highly dynamic and action-oriented, students were encouraged to verbalize their plans and actions rather than their underlying reflections and rationales. Even though they were encouraged to exchange opinions and needed to reach consensus during and after group discussions, their discourse was usually brief and concise. Identifying and capturing patterns of interaction in such brief communication was important for the analysis method.

These measures focused on identifying and categorizing the semantic nature of communicative interactions and were designed to determine the effect of group interaction and negotiation on decision-making. Six CA categories were identified: (a) Informative, (b) Argumentative, (c) Elicitative, (d) Responsive, (e) Directive, and (f) Off-task (see Table 3.3). For instance, coding categories include statements of agreement or disagreement between participants, clarifications of misconceptions, and the organization of understanding through the use of justifications, elaborations and expansions on arguments. In addition, other communicative functions, such as providing information,

asking questions and off-task comments were analyzed based on van Boxtel's analytic schema (van Boxtel, 2000).

Table 3.3. Categories Describing Communicative Activities

Category	Description	Example
1. Informative	Speaker provides information	
1.1 Statement	Communication	“We didn’t find any obvious signs of bleeding.”
2. Argumentative	Utterances may contain the following words	
2.1 Reason	“because”	“We should give oxygen because she’s had dyspnea.”
2.2 Condition	“if”	“Just to see if there is any, maybe, heart failure”
2.3 Consequence	“then, thus, so”	“The bolus helped him the first time. So I would bolus him again.”
2.4 Continuation	“and, then, so”	“And then we can look at what meds.”
2.5 Counter	“but”, “no + explanation”	“No, but it won’t show on the X-ray.”
2.6 Elaborate/Expand	A verbalization further explaining a previous statement.	“means like, we can see if airway is fine.”
2.7 Evaluation	One’s opinion or judgment related to the task	“No, that wouldn’t be good”
3. Elicitative	Speaker asks for addressee’s opinion.	

Table 3.3 (continued). Categories describing Communicative Activities

Category	Description	Example
3.1 Question	Asking for information and checking	
3.1.1 Verification	Checking ideas, opinion, or reasoning	"The vital signs?"
3.1.2 Open	Asking for new information	"What's our differential?"
3.2 Proposal	Suggestion for a common action	"We go see the patient?"
4. Responsive	Speaker reacts to an earlier utterance	
4.1 Acceptance	Neutral support	"Ok, crash cart"
4.2 Negation	Objection without explanation	"No"
4.3 Confirmation	Explicit support	"Yeah"
4.4 Repeat	Repetition of the previous utterance	"So we're gonna get the vital signs,"
5. Directive	Speaker gives an instruction or makes a suggestion	
5.1 Suggestion		"We should wait for the X-ray first."
5.2 Order		"You present the case"
6. Off task	Utterances irrelevant to problem solving task	

3.6.2 Computer Records

Digitized records of whiteboard writings and computer annotations were analyzed to characterize online argumentation activities (research question 3). Camtasia Studio, a software program was used to record student verbal protocols and screen videos of student laptop actions, such as references to the emergency algorithm and entered annotations. Camtasia Studio made it possible to discover how often students referred to the emergency algorithm and made whiteboard annotations, thus rendering verbal data more meaningful. It was assumed that students would refer to the emergency algorithm more often at the beginning of teaching sessions but might be more reluctant to annotate. As students gained experience, they referred to algorithm less frequently but made more annotations.

3.6.3 Post Test— semi-structured interview

Students were interviewed after the teaching sessions in to order assess their problem solving skills (research question 4). They were asked to provide retrospective verbal summaries on a different clinical case presented as a Quicktime video of an unknown case given to a previous different class. After watching the clip students were asked to provide a summary based on the following instructions:

1. Problem representation: (a) List the patient's problems (positive evidence), (b) List the most important problem(s) that needed to be attended to right now, (c) List the possible reasons for the most emergent problem(s), (d) If you were the role-play doctor in the video, what would you do differently?

2. Case management: (a) What further questions could you ask? (b) What results are you expecting? (c) What would you do to stabilize the patient?

3. Hypothesis and justification: (a) List the diagnoses or hypotheses for this patient, (b) Justify the questions, managements based on your expected results, (c) Explain the biomedical mechanisms of the patient's problem if you can.

Table 3.4. Coding of Post Teaching Interview

Category	Example
1. Interpreting the situation	
1.1 Listing positive evidence	"This patient is a 80 year old man with known diabetes and PUD, and he is also hypertensive, he's had infarcts before"
1.2 Situation awareness	"I would worry about him having any internal bleed or something"
2. Collecting patient data	"I would ask for blood pressure on both arms and I would ask for pulses on all four limbs."
3. Managing the patient	"There's basically not much to do just give him D50, as quickly as you can"
4. Meta-cognitive skills	
4.1 Making diagnosis	"I would think he is hypoglycaemic."
4.2 Giving explanations to the searching and managing	"I'd want a number because if it is low, if it is like 4 or something, it is a little bit low, if it is like 3 and below, then that would be worrying,"
4.3 Giving explanation to diagnosis	"Though you know I'm worried about the pressure, because I think he'd be tachycardiac, he'd be sweaty, he'd be all of those things. But I do not think he'd have high blood pressure."

3.6.4 *Microanalytic Method*

A microanalytic method was used to identify and explain differences in decision-making and communicative activities (research question 5). Microanalytical analysis is an important method for investigating learning processes in the sociocultural tradition. It holds that social activity, communication, and knowledge representation are inextricably bound together (Schoenfeld, Smith, & Arcavi, 1993). Such methods have been used to investigate how students construct joint problem spaces (Teasley & Roschelle, 1993) and group cognition (Stahl, 2005) through the use of cognitive tools.

Classroom discourse was segmented into several episodes to examine decision making and communication pattern of each stage in each group in order to show the difference between the CG and EG and the connections between the decision making and communicative activities between the two groups. Episodes in a discourse are semantic units that are characterized as coherent sequences of sentences (van Dijk, 1981).

3.6.5 *Data management and analysis*

Nvivo 2.0, a protocol analysis software program was used to code DMA, CA and post teaching interviews. For all activities, *trees of nodes* were used to create categories and subcategories that correspond to the meaningful utterances in the coding system. Nvivo provides reports of frequency for each category and subcategories. But only frequencies for first level nodes were used for statistical analysis.

Two independent raters rated 25% of the total protocol. Percentage of agreement is used for the inter-rater reliability. For DMA, the agreement of Planning is 88%, of Collecting data is 90%, of Managing is 79%, and of Interpreting is 87%. For CA, the agreement of Informatative is 92%, of Argumentative is 86%, of Elicitative is 89%, of

Responsive is 84%, and of Directive is 82%. For interview, the agreement of Collecting data is 89%, of Managing is 93%, of Interpreting is 87%, of Meta-cognition is 79%.

One variable of interest in this study was the sequence of decision-making. Since three sub-groups (abbreviated SG1, SG2, and SG3), took turns in managing the patient, it was of interest to see if there were any differences in DMA among SG1, SG2 and SG3. However, in this naturalistic decision making situations, it was difficult to allocate each SG equal time to solve the problem. At the beginning of the deteriorating patient activity when the patient's situation is less urgent and there were many questions that needed to be asked in accordance with the emergency algorithm. SG1 usually spends more time exploring the problem space by asking all kinds of questions. The teacher did not interrupt them while they continued to ask questions. Later on the patient's medical condition grew increasingly dire and most of the general questions had been asked by role-play students (See section 3.2 'Description of the Teaching Activity'). Time on information-seeking decreased and students were usually unable to come up with efficient management solutions either because of lack of expertise or not being able to focus on the most important issues. Students would then ask for help. This phenomenon is especially obvious for SG3 of each group. Table 3.4 summarizes the time each SG had on communicating and problem solving.

Table 3.5. Time (in minutes) Spent by Each SG across Different Sessions

	Control Group		Experimental Group	
	Session 1	Session 2	Session 1	Session 2
SG1	12min	12min	12min	11min
SG2	6min	7min	5min	8min
SG3	6min	6min	3min	5min

It can be seen that SG1 of both the experimental and the control groups spent more time than SG2 and SG3 of either group. To control for the time factor as a variable of stage, SG2 and SG3 were collapsed in data analysis. Thus, there are two sublevels of decision-making stage (DMS): early and later. This was done to see if time sequence had an effect on problem solving strategies. Based on an examination of audio and video tapes, it was found that due to time constraints and increased problem difficulty, SG3 usually had less time to solve the problem than did either SG1 or SG2. Thus, collapsing SG2 and SG3 makes the later level more equivalent to early level SG1.

Chapter 4: Results

Chapter 4 will present and discuss the results for each research question. Section 4.1 will discuss differences in the decision-making activities (DMA) between the experimental and the control groups. Section 4.2 will discuss differences in the communicative activities (CA) between the experimental and the control groups. Section 4.3 will discuss the results of an analysis of the argumentative activities expressed in the experimental group annotations. Section 4.4 will discuss the results of post teaching problem solving activities. Finally, Section 4.5 will examine the relationships between decision-making activities, communicative activities, and argumentation activities.

4.1 Decision-making Activities

Differences in the DMA between the experimental and control groups were examined using a Loglinear method due to the categorical nature of the variables. Loglinear analysis is chosen over chi-square test for its two advantages. The first advantage of this procedure is that it is easier to program in the case of a complex multi-way contingency table, since it allows all chi-square values to be derived through simple addition and subtraction of various combinations of the weighted logarithms. The second advantage is that Loglinear method provides more effective methods of analyzing high order interactions which is not possible with the chi-square test of independence. In Loglinear analysis, the first step is to compare different models and choose the one that best fits the data

4.1.1 Model selection

The four categorical variables in the four-way design are: (a) Group: Experimental (EG) vs. Control (CG), (b) Teaching Session: 1 vs. 2, (c) Decision-Making Stage (DMS): Early (SG1) or Late (SG2 and SG3), and (d) Decision-Making Activity (DMA): Planning, Collecting Data, Managing, and Interpreting. Cell frequencies were derived from protocol analyses of student decision-making activities.

Stepwise procedures were used in model selection. Effects were successively deleted according to the significance level of the likelihood ratio which represents model fitness and the significance of the effects left in the model. A saturated model was selected because the 4-way interaction Group*Session*DMS*DMA was statistically significant, $\chi^2 (3, N = 591) = 8.79$ at an alpha level of 0.05. In the saturated model, all the main effects, two-way, three-way, and four-way interaction effects are included. Please see Appendix 7 for the complete output. In the following table (Table 4.1), selected output is demonstrated for only significant results.

Table 4.1. Selected output of Model Selection: Saturated Model.

Source	<i>df</i>	χ^2	<i>p</i>
Group	1	4.24*	0.0396
DMS	1	4.65*	0.0311
DMA	3	71.52**	<0.0001
Session*DMS	1	19.89**	<0.0001
Group*DMA	3	8.65*	0.0343
Session*DMA	3	25.91**	<0.0001
Group*Session*DMS	1	12.35**	0.0004
Group*Session*DMA	3	7.32	0.0624
Group*DMS*DMA	3	15.95**	0.0012
Session*DMS*DMA	3	10.14*	0.0174
Group*Session*DMS*DMA	3	8.79*	0.0322

Note. * $p < .05$, ** $p < .01$

Table 4.1 shows the following significant results: (a) There are three significant main effects: Group, DMA, and DMS, (b) there are three significant 2-way interaction effects: Session*DMS, Session*DMS, and Session*DMA, (c) there are four significant 3-way interaction effects: Group*Session*DMS, Group*Session*DMA, Group*DMS*DMA, and Session*DMS*DMA. Group*Session*DMA is marginally significant, and (d) the 4-way interaction effects, Group*Session*DMS*DMA, is also significant.

4.1.2 Post hoc test

Post hoc comparisons were carried out to discover which effects explain significant interactions. Because the association between Group and DMA was of major interest, all effects involving these two variables were analyzed (See Table 4.2).

Table 4.2. Contrast Effects.

Contrast	Df	χ^2	P
<i>Contrast of Group*DMA</i>			
Group*DMA: Planning	1	12.33**	0.0004
Group*DMA: Collecting	1	3.02	0.0822
Group*DMA: Managing	1	0.18	0.6757
Group*DMA: Interpreting	1	0.00	0.9769
<i>Contrast of Group*DMS*DMA</i>			
Group*DMS*DMA: Planning	1	0.87	0.3502
Group*DMS*DMA: Collecting	1	0.32	0.5736
Group*DMS*DMA: Managing	1	4.59*	0.0321
Group*DMS*DMA: Interpreting	1	11.21**	0.0008
<i>Contrast of Group*Session*DMA</i>			
Group*Session*DMA: Planning	1	4.70*	0.0302
Group*Session*DMA: Collecting	1	0.41	0.5208
Group*Session*DMA: Managing	1	2.26	0.1324
Group*Session*DMA: Interpreting	1	0.25	0.6165

Note. * $p < .05$, ** $p < .01$

Table 4.2 shows the following significant results: (a) There is a significant contrast effect of Group*DMA in Planning, (b) there is a marginal contrast effect of Group*DMA in Collecting, (c) there are significant contrast effects of Group*DMS*DMA in Managing and Interpreting, and (d) there is a significant contrast effect of Group*Session*DMA in Planning.

Frequency counts and percentages are listed in cells for each interaction effect to better interpret the meaning of these statistically significant results (See Table 4.3, 4.4, and 4.5)

*Table 4.3. Frequency Distribution in Group*DMA.*

Group	DMA			
	Planning	Collecting	Managing	Interpreting
CG	75 (23%)	128 (40%)	39 (12%)	79 (25%)
EG	39 (14%)	101 (37%)	39 (14%)	91 (34%)

Table 4.2 shows there is a significant difference of Planning between the EG and the CG. Table 4.3 further demonstrates that the CG spent more effort (time) on Planning than EG.

*Table 4.4. Frequency Distribution in Group*Session*DMA.*

Group	Session	DMA			
		Planning	Collecting	Managing	Interpreting
CG	1	31 (20%)	53 (34%)	26 (16%)	48 (30%)
	2	44 (27%)	75 (46%)	13 (8%)	31 (19%)
EG	1	25 (17%)	37 (26%)	19 (13%)	62 (43%)
	2	14 (11%)	64 (50%)	20 (16%)	29 (23%)

Table 4.4 shows there is a significant difference in Planning between CG and EG across Teaching Sessions 1 and 2. CG planned less in teaching session 1 than in teaching session 2, while EG planned more than in teaching session 1 than in teaching session 2. Planning is the activity that was also coded in the communicative stage. The difference in Planning also implies the activity of communication.

*Table 4.5. Frequency Distribution in Group*DMS*DMA.*

Group	DMS	DMA			
		Planning	Collecting	Managing	Interpreting
CG	Early	46 (26%)	78 (44%)	21 (12%)	34 (19%)
	Late	29 (20%)	50 (35%)	18 (13%)	45 (32%)
EG	Early	23 (14%)	56 (35%)	15 (9%)	65 (41%)
	Late	16 (14%)	45 (41%)	24 (22%)	26 (23%)

Table 4.5 shows there is a significant difference between Managing the patient and Interpreting the situation. In the early stage of decision-making when the patient's situation is less urgent, EG gave less effort to Managing the patient but more to Interpreting the situation than CG did. In the late stage of decision-making when the patient's situation had become more urgent, EG gave more effort to Managing the patient but less to Interpreting the situation. Please refer Figure 4.1 for contrasts between the two groups.

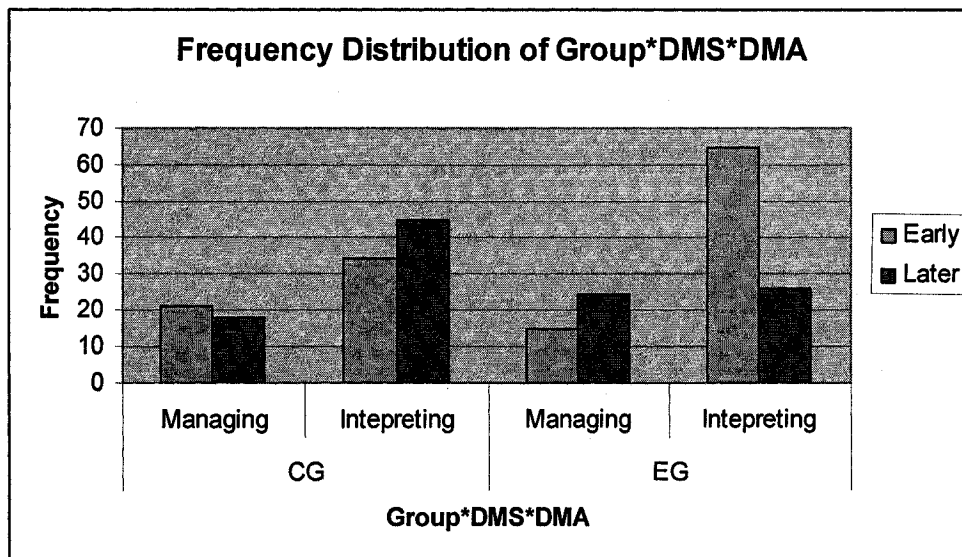


Figure 4.1. Frequency distribution of Group*DMS*DMA

Given the significant 4-way interaction effect: Group*Session*DMS*DMA, it is necessary to see if this 4-way interaction confounds the pattern and interpretation of the 3-way interaction of Group*DMS*DMA. Table 4.6 presents the frequency data for the 4-way interaction.

*Table 4.6. Frequency Distribution in Group*DMS*DMA across Two Sessions.*

Session	Group	DMS	DMA			
			Planning	Collecting	Managing	Interpreting
1	EG	Early	19 (17%)	26 (24%)	11 (10%)	53 (49%)
		Late	6 (18%)	11 (32%)	8 (24%)	9 (26%)
	CG	Early	22 (23%)	38 (39%)	10 (10%)	27 (28%)
		Late	9 (15%)	15 (25%)	16 (26%)	21 (34%)
2	EG	Early	4 (8%)	30 (60%)	4 (8%)	12 (24%)
		Late	10 (13%)	34 (44%)	16 (21%)	17 (22%)
	CG	Early	24 (29%)	40 (49%)	11 (13%)	7 (9%)
		Late	20 (25%)	35 (43%)	2 (2%)	24 (30%)

Different patterns of 3-way interaction are indicated across the two teaching sessions. When running two separate contrasts, Interpreting shows significant contrast effect in session 1, $\chi^2 (1, N = 301) = 11.76, p = 0.0006$. Managing the patient shows significant contrast effect in session 2, $\chi^2 (1, N = 290) = 14.30, p = 0.0002$. For example, the EG put twice the time in interpreting the situation in the early stage in session 1 (49%), and in session 2, their interpretation behavior was lower in the early stage (24%). In contrast, the CG spent about the equal time in interpreting the situation in the Early and Late stage in session 1. However, in session 2, they spent much more time (30%) in the late stage than early stage (9%). As to managing the patient, the CG and EG had a similar pattern in session 1. However, they started to demonstrate big discrepancy in

session 2. The EG's management activities increased dramatically in the late stage. However, the CG's management activities decreased dramatically.

4.2 Communication Activities

Research question 2 focused on whether there were any differences in the communicative activities (CA) of EG and CG. The total 'deteriorating patient' activity took between 30% and 50% of each teaching session. During this time, students did not communicate a great deal even when asked and encouraged to do so. The reason for this is that students were not used to solving problems collaboratively in situations where they were expected to work quickly, carefully and accurately under pressure. As students worked together to reach solutions while the patient's condition fluctuated, they tended to communicate with the teacher instead of discussing the situation with their peers. Consequently, the number of communication activities was small, compared to the number of decision-making activities. Five CA coding categories were identified. There is no off-task discourse during the role play stage which implied that the students were highly focused on their work while engaged in urgent decision making.

The Logliner method was used to look for correlations between Group, Teaching Session, decision-making stage (DMS), and CA. Cell frequencies were derived from protocol analyses of student communicative activities, however the frequencies were quite low. The low frequencies could explain why no significant differences were found. In order to discover CA patterns between EG and CG, descriptive methods are used. Frequency distributions are listed in Table 4.7, 4.8, and 4.9.

*Table 4.7. Frequency Distribution of Group*CA.*

Group	CA				
	Informative	Argumentative	Elicitative	Responsive	Directive
CG	9 (8%)	39 (35%)	23 (20%)	27 (24%)	14 (13%)
EG	25 (17%)	35 (25%)	27 (19%)	38 (27%)	17 (12%)

Table 4.7 shows the following findings: (a) Overall the EG produced more communicative activities than CG, and (b) the EG produced more Informative and fewer Argumentative utterances than CG.

*Table 4.8. Frequency Distribution of Group*DMS*CA.*

Group	DMS	CA				
		Informative	Argumentative	Elicitative	Responsive	Directive
CG	Early	3 (4%)	30 (41%)	13 (18%)	17 (23%)	11 (14%)
	Later	6 (16%)	9 (24%)	10 (26%)	10 (26%)	3 (8%)
EG	Early	19 (21%)	27 (30%)	19 (21%)	18 (20%)	8 (9%)
	Later	6 (11%)	8 (16%)	8 (16%)	20 (39%)	9 (18%)

Table 4.8 shows more communicative remarks were produced in the Early stage by both groups, except that CG produced more Informative remarks in the Late stage.

*Table 4.9. Frequency Distribution of Group*Session*CA.*

Group	Session	CA				
		Informative	Argumentative	Elicitative	Responsive	Directive
CG	1	2 (4%)	20 (41%)	11 (22%)	11 (22%)	5 (10%)
	2	7 (11%)	19 (30%)	12 (19%)	16 (25%)	9 (14%)
EG	1	17 (20%)	24 (28%)	19 (22%)	18 (21%)	7 (8%)
	2	8 (14%)	11 (19%)	8 (14%)	20 (35%)	10 (18%)

Table 4.9 shows CG produced relatively fewer Informative remarks in Session 1 and more in Session 2 than EG. CG engaged in relatively more communicative activities in Session 2 and EG engaged relatively more communicative activities in Session 1.

4.3 Argumentation Activities

Research question 3 examined the characteristics of online argumentation activities in EG annotations.

While subgroup one (SG1) was solving the problem, subgroup two (SG2) and subgroups three (SG3) made annotations on their laptops and used the Ebeam technology to share their annotations with their peers. Likewise while SG 2 was solving the problem, SG1 and SG3 made annotations.

First, all annotations were examined and three themes were identified:

1. Disagreement. When an observer disagreed with giving “2 liter oxygen to the patient by nasal prongs” he placed a question mark in front of it (“? 2 liter oxygen to the patient by nasal prongs”) to emphasize his disagreement.

2. Proposal. “Baseline BP? Give 100 mg iv cortisone” means that the observer proposed checking “baseline blood pressure” and giving “100 mg cortisone intravenously”

3. Interpretation. “Relevance of prednisone” means that the observer thought the patient’s problem could be related to prednisone.

83.9% of the annotations are Proposals recommending alternatives, 12.9% suggest alternative Interpretations, and 3.2% express Disagreements with some action.

Second, annotating acts were examined with respect to when they occurred and how they influenced decision-making and vice versa. A microanalytic method was used for this purpose.

Effects of decision-making activities on annotation

Observers used the interactive whiteboard to record plans for Collecting data or for Managing the patient, as role-play decision-makers solved the problem. Observers did not rush to post their ideas right away. If they found that a decision-maker later expressed the same idea, they would erase their original annotation. If they thought their ideas might be useful, they would post them for others to see. For example, in Teaching Session 1, when SG1 mentioned giving oxygen to the patient, SG2 wrote ‘2 liter nasa(l)’, to suggest giving oxygen with nasal prongs at a speed of 2 liters. SG2 did not post it because SG1 continued to argue for giving oxygen right away. SG1 eventually decided to give oxygen by nasal prongs and SG2 erased their annotation. Later on, SG2 wrote ‘? 2 liter prongs’ to indicate that they did not quite agree with SG1’s suggestion of ‘giving 5 liters by nasal prongs.’ SG2 added a question mark to get SG1’s attention. See Appendix 1 for an example of the effects of decision-making activities on whiteboard annotations.

Effects of annotations on decision-making activities

On decision-makers. Annotations began to play a role in the later stage of the case as the patient's situation grew increasingly urgent. Decision-makers tended to take suggestions from observer annotations. E.g., in Teaching Session 1 an SG1 student asked about 'medication', 'blood glucose' and 'blood culture' based on annotations provided by SG2 and SG3. This suggests that as the problem becomes more difficult, students become more open to the opinions of others.

On Annotators. If an annotator's annotation was not taken up by others, the annotator would take it up as soon as they got a chance to work on the problem. E.g., the first thing SG2 did when their turn came was to ask about 'lung auscultation' which they had annotated while SG1 was working on the problem. The first thing SG3 when their turn came was to ask about 'blood glucose' which they had written while SG1 was solving the problem.

Referencing behavior

Students were also provided with a reference tool in the form of a dropdown menu in which the 'ABCDEF' emergency algorithm was embedded. Referencing behavior was examined according to time, frequency, duration, and content of referencing.

SG1 did not refer to the online algorithm during the deteriorating patient activity.

SG2 began checking the reference tool after they had posted some annotations. They quickly went over subcategories 'Airway' and 'Breathing' and stopped at subcategory of 'Circulation'. SG2 quickly moused over each item in each category. They stayed on this screen for more than 10 minutes and towards the end of Teaching Session

2, they annotate more information. It was difficult to discover a direct relationship between referencing behavior and discourse patterns.

SG3 first checked 'Drugs', then checked 'Circulation/CNS/Cervical spine' and 'Breathing', went back to 'Drugs', and then to 'Endocrine/Metabolic'. SG3 did not use the mouse to highlight items in each category even though the students might have read all of them. They checked 'Drugs' twice but it did not demonstrate any connections between this behavior and further discourse or annotations.

In general, referencing acts were very brief and there were no obvious patterns, e.g., there were no annotations immediately after referring to the algorithm; there were no obvious connections between discourse and the referencing acts.

4.4 Post Test

Question 4 asked whether EG and CG post teaching interviews revealed different problem solving strategies. A two-way ANOVA was used in the analysis. One of the factors is Group, being the EG and CG. The other factor is decision-making activities (DMA) comprised of Interpreting the situation, Collecting the information, Managing patient, and Meta-cognitive skills. The dependent measure is the number of meaningful units of student think-aloud decision-making protocols. No significant main or interaction effects for Group, DMA and Group*DMA (Table 4.10).

*Table 4.10. 2-way ANOVA Output for Group*DMA.*

Source	<i>df</i>	F	<i>P</i>
Group	1	6.99	.114
DMA	3	4.89	.072
Group*DMA	3	1.51	.224

4.5 Decision-making, Communicative, and Argumentative Activities

Question 5 asked about the relationship between decision-making activities (DMA), communicative activities (CA), and argumentation activities. Sections 4.1, 4.2, and 4.4 used quantitative methods to examine differences in CA and DMA and between EG and CG. This study examined how students make decisions collaboratively with the support of shared visualization and argumentation tools and it was assumed that collaborative tools that mediated communication because of shared visualizations should promote the co-construction of joint problem spaces and collaborative argumentation. A qualitative exploration was necessary to understand differences in these activities with respect to EG and CG and possible relationships among CA, DMA and how students use collaborative tools. Such an exploration can illuminate methodological issues pertaining to the exploration of alternative ways of discovering implicit relationships among different aspects of collaborative decision-making.

A microanalysis method was used to discover qualitative relationships and mechanisms among variables. The idea pursued here is to examine how collaborative tools facilitate the construction of shared cognition in collaborative decision-making.

This section will present examples representing the different stages of collaborative decision-making discourse from one teaching session of each group to demonstrate differences in decision-making and communication activities. Three episodes were identified in the transcripts to differentiate these activities between the two groups. In Episode 1, students discussed background information provided by the teacher about the deteriorating patient and questioned the Nurse about the patient current situation. This stage can also be called data collection and involved little conflicts. Episode 2 began when the teacher initiated the deterioration of the patient forcing the students to stabilize the patient. By causing the patient's vital signs to deteriorate in episode two the teacher forced students to take decisive actions that could either help or have no effect. Conflicts started to emerge as to what actions should be taken. In Episode 3, with the increasing deterioration of the patient, both EG and CG had difficulty communicating because they did not know how to proceed.

4.5.1 DMA and CA at Different Stage

The cases for EG and CG are similar except for slight differences in descriptions. Here is the example from EG.

It is Saturday evening, 9 PM, you're asked to see an 80 year old male who was admitted to your floor. The gentleman has hypertension, type II diabetes, Polymyalgia rheumatica PMR. He was admitted for a left lower lobe pneumonia. The nurse asks you (to) see the patient, because... I am the nurse. ...he looks "sick". So first group, I'm the nurse, you're the doc, what you are going to do?

Episode 1: At the beginning of the case, students were asked to discuss plans for data collection and patient management. CG students had a short, superficial discussion

in which they threw out information and gave no details about how to examine or manage the patient. M, O and P are students.

Excerpt 1

M: First thing we ask for the vital signs?

O: Yeah.

O: We should ask the nurse for the vital signs and at the meantime go to see the patient ourselves. Uh, and we can ask someone to get, and we can ask the nurse over the phone how bad does the patient look.

M: And if it's very bad, we can call the residents while walking to see the patient.

O: We can ask them to bring the chart also, just to have all the information that we are going to need at bedside.

M: And see which also what meds he is taking and see if he is on any antibiotic.

Here M proposed something and O accepted and elaborated it. Students provided information which was assumed to be common knowledge. For example, O elaborated on his proposal as “*We should ask the nurse for the vital signs and in the meantime go to see the patient ourselves. Uh, and we can ask someone to get, and we can ask the nurse over the phone how bad does the patient look*”. M added “*And if it's very bad, we can call the residents while walking to see the patient*”. Even though the communication seemed to be smooth and there was little conflict at this stage, no in depth discussion about patient's problem occurred. However simple communication such as informing each other about

the daily routines of medical practice can help build up a shared understanding of the situation for further collaboration.

EG engaged in similar communication later in the problem solving session. Here is a similar discussion.

Excerpt 2

T: OK. (Continues drawing for 20 seconds) So his O2 SAT is 95 percent, his temperature is 38 degrees, his respiratory rate is 24 per minute, and his heart rate is 100 a minute. And his blood pressure is 100 over 60.

P: Pressure.

M: Hmmm?

P: Blood pressure.

M: Yeah, Hypertensive, that's low. He is in afib, his heart rate is getting tachy. He's breathing quickly.

P: (And) The O2 SAT is 95.

M: (Yeah), The O2 SAT is 95.

The teacher presented the patient's vital signs. P said '*pressure*' to get M's attention to the patient's blood pressure because the patient had history of high blood pressure, but his pressure is not high now. M was not quite clear what that meant. P elaborated by saying '*Blood pressure*', M understood and went on to say that the patient had a history of hypertension, but now with low blood pressure. M also continued to elaborate other symptoms, such as '*his heart rate is getting tachy.*' P continued to inform the oxygen saturation state and M repeated the information to show his awareness.

CG and EG demonstrate similarities at this stage as to the information they communicated, which are either common knowledge, such as ‘get vital signs’, or the information has been introduced by the teacher. The excerpts above indicate that in the early stage of the activity, students tended to talk about the situation and to build a shared understanding of the problem. Commonly used words such as “and”, “if”, and “then” are commonly used in Argumentative discourse activities. Frequency distributions (Table 4.8) indicated that both CG and EG had demonstrated more Argumentative discourse in the early stage, 41% and 30% respectively. Discourse features such as reason, elaboration, continuation, and condition indicated smooth turn-taking patterns which reflect productive collaborations. The discourse patterns identified in Episode 1 indicate the production of shared problem-solving knowledge. Students communicate based on what they say to each other. One student begins a sentence/idea and another finishes it.

Episode 2: A conflict occurred in the CG towards the end of SG1’s performance after they collected most of the relevant data according to the ‘ABCDEF’ emergency algorithm.

Excerpt 3

M: So I would ask the blood test?

O: I think we should examine the patient though.

M: Sure, lung exam? (to O)

After asking a series of questions and collecting some negative data, M proposed to O that they ask for a blood test, but O disagreed and suggested that they examined the

patient, and M immediately agreed without argument. This pattern was repeated later on in SG1.

Excerpt 4

T: Bolus of NS? Yes, doctor? How much would you like to give him? (The teacher acted as the nurse and inquire how to bolus the patient)

O: Uh, five hundred.

M: Would you be...

O: (interrupts M) Listen to the heart before, listen to heart before?

M: Just to see if there is any, maybe, heart failure. In that case we would have to be careful if we give any saline. (because) We do not want to overload the [patient].

O first proposed that they bolus the patient but M proposed that they check the patient's heart before bolusing him. M took up O's suggestion and elaborated on why they should listen to the patient's heart before bolusing him. Towards the end of the early stage of problem solving, CG started to exchange opinions about collecting data and patient management. Even though there were conflicts, students tended to reach agreements without much negotiation. Rather than increasing the number of argumentative activities the discourse revealed more Elicitative and Responsive patterns indicating acceptance rather than a negotiation of opinions. However one of the students tended to dominate the discourse.

When the EG group was at a similar stage in problem solving, two SG1 students ran into the same difficulty toward the end of their turn. They consulted the annotations and began a discussion.

Excerpt 5

M: Another bolus? OK, Glucose. Another bolus. And do we want to... Ah meds?

He could be taking sort of (meds). That could (cause the problem). Has he taken an antibiotic lately that could have... Sounds medications. Complete blood count. OK, is that alright?

P: Hmmm.

M: Sounds like medications could play a thing?

P: Hmmm.

M: Is that alright?

P: Before that we should bolus him again?

M: We should bolus him again. The bolus helped him the first time. So I would bolus him again.

P: And then we can look at what meds he is taking.

After consulting the annotations, M mentioned ‘glucose’, ‘another bolus’, and ‘meds’ and then focused on ‘meds’ and suggested that the patient’s problem could have been caused by medications. P agreed by saying ‘Hmmm’ but then added that in addition to ‘medication’, ‘bolus’ should also be considered. M agreed with her by adding a justification to this plan that ‘The bolus helped him the first time. So I would bolus him

again'. Then P added her opinion about 'meds'. It can be seen that P and M spent the same amount of time contributing to the dialogue about what data to collect and how to manage the patient. Shared understanding of the situation is achieved by communication. This phenomenon is consistent with the findings demonstrated in Table 4.8 which indicated the EG had relatively more informative but less argumentative utterances of problem solving.

Episode 3: In the later stage of the deteriorating patient activity (SG 2 and SG 3), even though students ran into difficulty, they did not know what to discuss even when the teacher told them to do so. Following is an example from CG. S and E are students.

Excerpt 6

T: Blood culture is negative. And let's say the CBC comes back showing a ah...

We just wanna be realistic here. I'll give you a white blood cell count of 11, a hemoglobin of 135, platelets of 300,000.

T: So discuss among yourselves. Try to work it out.

(S & E Confer)

T: Talk louder. We can't hear you.

S: What we're discussing?

T: Yeah.

S: OK.

S: His platelets are sky high. I don't know should we...?

E: Yeah.

S: So what do you think?

E: I think about... How's his lytes?

T: His electrolytes doctor?

Before this excerpt, S and E asked for information about complete blood count (CBC) and were told that platelets were 300,000. The teacher told them to discuss among themselves. Both thought that the platelets were high. S asked '*So what do you think?*' E said '*I think about...*' but didn't finish the thought. E then asked the teacher for more information '*How's his lytes*'. The rest of their discussion was similar. S and E offered no concrete ideas or proposals and there was no argumentation or elaboration.

EG produced little spontaneous discussion except in the final stages where a disagreement erupted. N & Y are students.

Excerpt 7

N: I am not sure we should um, give epinephrine.

...

N: He's not responding to fluids.

Y: We should wait for the X-ray first. [As to] epinephrine or vasopressin. I don't know.

N: No. No. You can't wait for the X-ray like when the blood pressure is going down like that.

N: (To T) We're thinking of give like vasopressin or epinephrine.

T: Um-Hm.

N: Because like waiting for the X-ray and stuff is taking a while and the patient is crashing, so we can bolus. Like is it one milligram epi? One?

T: So you're thinking of giving vasopressin?

N: Yeah.

Y: Or epinephrine.

N: Yeah.

Here, '*epinephrine*', '*fluids*', and '*X-ray*' were introduced by annotations or mentioned by the previous SGs. N expressed her confusion about whether or not they should '*give epinephrine*', and responded to an annotation about '*bolus*' that she thought it didn't work because '*He's not responding to fluids*'. Y proposed that they should wait for the results from the X-ray and was uncertain with respect to '*epinephrine or vasopressin*' as well. N responded by disagreeing about '*X-ray*' and then told the teacher about their plan of giving Vasopressin or Epinephrine. Then N explained why she did not agree '*waiting for X-ray*'. Y conceded and added the supplemental information '*or epinephrine*' and N agreed. Discourse topics, in the late stages of decision-making, were often triggered by outside opinions in the form of annotations. Although students came into conflict they also tried to justify their opinions in order to reach consensus.

CG and EG students demonstrated similarities and differences at various stages in the activity. Both groups engaged in short, superficial discussions to build shared understandings of the patient's situation during the early stage. During the middle stage, both groups argued about how best to solve the patient's problem. CG students quickly reached agreement on data collection and patient management but with one student dominating the discourse whereas EG students reached agreement through equal contributions which implied that they had constructed shared understandings through communication. In the late stage, both groups ran into difficulty solving the case. CG students engaged in few decision-making activities and their discourse exhibited little

argumentation or elaboration. EG students produced relatively more decision-making acts which were often triggered by electronic whiteboard annotations.

4.5.2 Content of Communication

Student behavior while using the interactive whiteboard can be characterized in terms of their verbal discourse. During the early stage of decision-making when there was no imminent pressure of the deterioration of the patient, SG1 of the experimental group asked all kinds of questions relating to the patient's situation and tried to identify possible reasons for the patient's deteriorating condition. However, because they were not on the right track in their questioning, the patient's vital signs kept on deteriorating. When the teacher asked '*What are you going to do?*' the students responded '*Not really going to say*' which indicated that they did not have further ideas. The students then referred to the annotations on their laptops, but they were not sure what they were supposed to do, so they asked the teacher '*We can see all their comments?*' The teacher said '*I know, I know that's the whole point*' to confirm their inquiry. The above discourse demonstrated that initially students were not quite clear about the purpose of the tools but from that moment students' decision-making and discourse could have been influenced by the annotations.

Later on, the students' decision-making activities as indicated by verbal interactions were directly or indirectly influenced by the interactive whiteboard annotations. SG1 students began asking questions based on such SG3 annotation as '*what meds he's on?*'. One medication he was on was "*prednisone*" and this information influenced their later interaction. SG1 students discussed whether the prednisone should be discontinued. P (in SG1) proposed stopping Prednisone, while M (in SG1) was worried about whether stopping steroids too suddenly would result in the patient going '*cold*'

turkey', an acute withdrawal reaction that can lead to a crisis situation. A large stretch of the following conversation focused on this topic and was mainly *informative and argumentative*. These examples support the frequency distribution results in Table 4.8 which showed that in the early stage, EG has more informative and argumentative utterances. From a decision-making perspective, it is obvious here that most of the activity involved *interpreting* the situation. This explains the results of Group*Decision-making stage (DMS)*Decision-making activity (DMA) that in the early stage (SG1) of decision-making, EG showed significant more Interpreting activity which is supported by informative and argumentative behavior.

SG2 was mainly concerned about checking the lungs. SG2 wrote on the interactive whiteboard '*listen to the lungs*' before their turn came, and SG3 wrote '*CXR/C*' which means chest X-ray. The whole discussion in this teaching session was about checking the lungs. Their first question "*have you listened to his lungs*" reflected their concern about this issue since SG1 failed to deal with the lungs. SG2 also thought chest X-ray which was also suggested by SG3. The only other question asked was "*fluid intake*" which was also annotated by SG2. A similar pattern was also seen with SG3 whose data collecting was directed by their earlier annotations or by those of other subgroups. Management actions were also influenced by the opinions of others, which gave rise to discussions and reflections (interpretation).

It is obvious that SGs took the interactive whiteboard annotations into consideration in the later stages of decision-making, especially in Teaching Session 2. Suggestions for collecting data and managing the patient were taken into consideration

and this may explain why EG spent more time managing the patient than CG in later stage of the teaching session.

4.5.3 Pattern of Interaction

This section will identify pattern of interactions that characterize differences between EG and CG.

During the deteriorating patient activity, students were always encouraged to discuss problems themselves. However, when they encountered a problem they rarely talked about it. This was more obvious in CG. For example in Teaching Session 1, the teacher gave CG explicit instructions to discuss problems among themselves. For example, students B and G had different plans for the patient, B told the nurse to check the patient's 'ECG' and G proposed giving the patient 'Dextrose'. Here is an example.

Excerpt 8

T: You better discuss among yourselves. I mean one of you is telling me dextrose and the other is telling me ECG. You guys have to decide.

(B & G Confer)

B: So? (To G)

G: Is dextrose ok with you guys? (To B) 5 percent with saline.

B: Yes, I think we could give him dextrose.

B and G had a brief communication after the teacher's instructions because they had different proposals for the patient. However, the discussion was very brief. B asked G's opinion who then gave his proposal which B immediately accepted. A similar pattern occurred later on when G and B talked about giving more liquid.

Excerpt 9

T: More bolus? Discuss among yourselves.

G: Can we give more bolus? Just feel like he maybe crash.

B: Yes, could give bolus and [...] after

G: And actually, at the meantime we're cross matching some blood.

T: So what you are saying is get off a cross match, ok, and we will give another bolus of what?

B: Dextrose.

G: Can we bolus with dextrose? (talk to B)

B: No.

G: No, that wouldn't be good.

The discussion was brief with little argumentation. Even though G and B disagreed initially, they came to an agreement with little negotiation. The same pattern could be seen in the rest of the problem solving episodes.

As demonstrated above, CG interactions were brief and involved little negotiation and elaboration. Their discussion is not spontaneous and usually needs teacher's instruction.

EG discussions involved more turn taking and students contributed more equally in terms of offering ideas. EG students seemed to express their opinions and the teacher seldom interrupted or pushed them to collaborate. Their discussion was led by ideas from annotations. Refer the same example of Excerpt 5.

M read the annotations and repeated, i.e., 'glucose', 'another bolus', and 'meds.' M then began elaborating possible reasons for the problem, such as taking inappropriate medication. P agreed and suggested that they 'access his chart'. M then proposed to treat

the patient with another bolus. P did not object but insisted that they should also check the patient's medications.

4.6 Summary

This section presents results for each research question. A Loglinear method is used to examine the differences of decision-making and communicative activities between the experimental and control groups. Statistically significant results showed (a) CG students plan more than EG students, (b) This significant difference in Planning occurs across Teaching Session 1 and 2. EG planned more in teaching session 1 but less in teaching 2 than CG, (c) There is significant difference between Managing and Interpreting between CG and EG across Early and Late stage. In the Early stage, EG managed less but interpreted more than CG. In the Late stage, EG managed more but interpreted less than CG. There is no significant difference of communicative activities between CG and EG students. Descriptive frequency analysis showed both EG and CG students produced more communicative utterances in the Early stage, except that CG students produced fewer Informative utterances in Early stage and more in Late stage than EG students. There is no significant post test difference on problem solving strategies between the CG and EG students. Qualitative analysis was used to examine (a) the characteristics of online argumentation, and (b) relationships among decision-making, communication and argumentation. CG and EG started to demonstrate differences when they had conflicts or ran into difficulties while solving the problem. EG tended to have more collaborative argumentation and elaboration which could be triggered by opinions from whiteboard annotations which further lead to more decision-making activities.

Chapter 5: Discussion

This section will first summarize the characteristics of collaborative decision-making in emergency situations in order to help contextualize the deteriorating patient activity and the rationale of this study. The results of the five research questions and their results will then be discussed. The implication of future research is discussed focusing on how to design intelligent management tools in such environments and how to extend it into interactive environments. Finally, contributions, limitations of this work, and conclusion will be presented.

5.1 Characteristics of Collaborative Decision-making in Emergency Situations

The purpose of this study was to investigate differences in collaborative decision-making and communicative interactions in a simulated medical emergency situation under two conditions: the traditional whiteboard (CG) condition or the interactive whiteboard (EG) condition. It was hypothesized that interactive whiteboards augmented with shared visualization and argumentation tools would give rise to differences in decision-making and communicative activities. A cognitive framework based on a detailed bottom-up examination of decision-making discourse was developed to identify differences in the decision-making activities of EG and CG students. Four iterative decision making processes were identified: (a) Planning, (b) Collecting Patient Data, (c) Managing the Patient and (d) Interpreting Patient Situation.

After providing students with information about the case, the teacher instructed them to plan to collect data about the patient in order to manage his/her condition. Students were then told to implement their plans and were provided with immediate

feedback (patient's results) corresponding to their data collection and patient management actions by the teacher acting as nurse or as patient. Students used such feedback to interpret, plan, collect additional patient data, and implement further management actions. By discussing the patient's symptoms, history, and results, the students constructed complex shared understandings of the situation. Students' shared understandings often lead them to review various aspects of each 'deteriorating patient' case. This cyclical process was found to occur as learners collaboratively constructed shared understandings and made management decisions about the deteriorating patient.

The four decision-making processes identified here are similar to the six clinical decision making processes identified by Lajoie and colleagues (Lajoie et al., 1998) in a study of ICU nurses: (a) generating hypotheses, (b) planning medical interventions, (c) performing actions, (d) gathering evidence, (e) interpreting the results, and (f) overall solution paths. However, in contrast to Lajoie et al (1998) and other traditional studies of medical problem solving, this NDM study of simulated medical emergencies found that the process of generating hypotheses to be less relevant. This may be because the priority in medical emergencies is to stabilize the patient and to rule out life threatening contingencies. In laboratory-based studies of problem solving (Patel & Groen, 1986), participants are required to make diagnoses so that researchers can test their hypothesis with respect to direction of reasoning (forward or backward), or diagnostic accuracy. Understanding differences between real-world and laboratory settings can help to bridge the gap between satisfying research interests and the need to improve teaching and learning in real-world settings. Understanding these differences can lead to better designs of authentic CBLEs.

The delivery of emergency medical care typically involves teams of medical professionals working in highly organized technological and institutional environments. Research on collaborative NDM shows that decision-makers rely on (a) shared task models, (b) effective communication skills, (c) acute situational awareness, and (d) meta-cognitive skills (Orasanu, 2005). Shared task models are composed of highly integrated jointly held systems of knowledge (Orasanu & Salas, 1993). For instance, all emergency medical care physicians know the 'ABCDEF' emergency algorithm for dealing with medical emergencies. This algorithm provides them with a common basis for communication and collaboration which in turn further supports and facilitates their ability to plan and act. Furthermore, as medical emergency situations develop so must the complexity of the shared understandings that enables medical teams to collaborate effectively (Orasanu & Salas, 1993). Effective communication skills enable collaborators to construct the complex shared understandings that provide contexts for interpreting collected results and making patient management decisions. In order to quickly and accurately assess a patient's rapidly changing medical condition, team members must communicate with each other and perhaps with other medical professionals. This communication facilitates the construction of shared understandings of goals, plans and actions for managing the patient. Meta-cognitive skills include the ability to develop and maintain an awareness of such situational demands as "what needs to be done; what resources are required; what capabilities do I have; how can I manage in this situation" (Orasanu, 2005). In emergency medicine, meta-cognitive skills enable students to reflect on their ability to solve problems and to seek assistance when they realize that they cannot solve the problem.

Investigating the cognitive characteristics of collaborative NDM provides the rationale for designing the CBLE used in this study. An electronic ‘ABCDEF’ emergency algorithm in a dropdown menu format was added so as to be accessible to all participants. Dynamically changing patient situations were electronically recorded on patient charts and shared by group members via electronic whiteboards. This study demonstrated that the visualization of shared information can facilitate face-to-face communication and collaboration in urgent situations. Students can also use online annotation tools to propose plans or comment on each other’s decisions. This facilitates decision-makers’ meta-cognition as if they should take other’s opinion or seek for assistance.

Understanding the cognitive characteristics of collaborative NDM has three advantages for future studies: (a) identifying and describing further expert-novice differences in order to support the development of CBLEs to support medical decision-making, (b) evaluating student performance in both real-life and simulated settings, and (c) designing and implementing team tasks.

5.2 Multiple Perspectives

The goal of this study was to identify, examine, and account for differences in the decision-making and communication activities of medical students engaged in the ‘deteriorating patient’ activity under two conditions: the CG condition using a traditional whiteboard and the EG condition using a structured interactive whiteboard. Decision-making activities were viewed as processes as opposed to products and activities were embedded in a simulated naturalistic decision-making environment as opposed to a laboratory setting. The research also focused on collaborative as opposed to individual

decision-making activities. Technology was used to support and hopefully enhance decision-making processes. All of this rendered the decision-making activities more similar to problem solving activities. However, in contrast to classical problem solving studies which focus on diagnostic reasoning and knowledge structures, this study focused on the decision-making actions arising from the 'deteriorating patient' learning activity.

This study used both quantitative and qualitative methods to examine collaborative NDM from cognitive, social and technological perspectives. Quantitative methods were used to identify differences in CG and EG student decision-making and communicative activities. Qualitative descriptive methods such as microanalytic methods were used to identify and describe relationships among communicative, decision-making activities, and technology using behaviour. Other studies have used quantitative methods to examine correlations between discovery learning and communication (Okada & Simon, 1997; Saab et al., 2005). Qualitative methods have shown that shared visual representations of knowledge are important in collaborative problem solving (Roschelle & Teasley, 1995; Stoyanova & Kommers, 2002; Teasley & Roschelle, 1993).

5.3 Decision-making, Communication, and Cognitive Tools

CG and EG showed differences in Planning when only Group variable (control group vs. experimental group) is considered. Table 4.3 shows that EG students plan less than CG students. Planning is the activity in which students work together to formulate plans for collecting patient data and for managing the patient's condition. It is the process whereby students discuss, negotiate and determine what they should do in order to better understand the patient's problems and to more effectively deal with them. EG students may have planned less than the CG students because given the scaffolding they receive

from the collaborative tools, they spent less time discussing planning but put more effort on other more important decision-making activities, such as managing the patient.

Interactive whiteboards were designed to provide students with argumentation and visualization tools. Argumentation tools allowed observing students to annotate and display patient situations and the actions of decision-making students thus providing decision-makers with additional opinions. Tools for visualizing such representations scaffolded student decision-making by displaying problem states and by making the 'ABCDEF' emergency algorithm available for easy reference. Visualization and argumentation tools help EG students construct complex common understandings in order to promote more effective communication and decision-making. Interactive whiteboards when structured by results from cognitive analysis can result in the design of cognitive tools that assume some of the cognitive work that is supposed to take place in face-to-face communication thus reducing the time and cognitive resources that students must invest in planning. Instead of attempting to develop plans for managing the patient, students went directly to patient management actions because they adopted observer annotations and developed shared situation understandings. This assumption will be verified later while correlating evidence from interactive whiteboard annotations.

When other variables are taken into consideration, differences in other CG and EG decision-making activities emerged. The Planning effect emerged when the variable Session (Teaching Session 1 vs. Teaching Session 2) was added (Table 4.4). In Teaching Session 1 EG students planned more than the CG students, but in Teaching Session 2, they planned less than the CG students. Given that planning is a collaborative activity, it is possible that collaborative tools facilitated students' collaboration for planning at

Teaching Session 1 and helped to build familiarity and the experience of working together. In Teaching Session 2, EG students have developed more experience in communicating for planning, and are more familiar with collaborative tools that give them additional opinions. Thus, their communication for planning is more efficient and effective, perhaps because it is more implicit. This is supported by the fact that there are significantly fewer planning-related utterances in the transcript. This finding is consistent with the assumption that visualization and annotation tools enhanced the interactive whiteboards technology and facilitated the development of shared understandings of problem situations, based on which subsequent solutions were built. Thus, students invested less effort in planning given that students who had preceded them had annotated their plans.

When Stage variable (Early vs. Later) was added, the Interpreting and the Managing effect became significant in a 3-way interaction. In the early stage when the patient's situation was less dire, EG students managed less and interpreted more than CG students. In the later stage as the patient's condition grew increasingly dire, EG students managed more and interpreted less.

These results above indicate that in the early stage EG students spent more time interpreting patient history, laboratory tests, and vital signs perhaps in order to construct shared understandings or to reflect on these aspects of the patient. At this stage, EG students tended to engage in fewer management actions. In the later stage as the patient's situation grew increasingly dire, EG students tended to engage in more management actions to stabilize the patient. In contrast, CG students interpreted less in the early stage but more in the later stage. They also manage less in the later stage.

When Teaching Session was taken into consideration, different patterns of 3-way interaction emerged (Table 4.6). For the EG group, students' interpretation behavior tended declined in the early stage in session 2 compared to session 1. More effort was put on data collecting which shows an increase from 24% to 60% in the early stage from session 1 to session 2. Meanwhile, the EG do put more effort into managing the patient when the patient situation deteriorated in session 2. However the CG group showed decreased patient management in the late stage in teaching session 2 compared to session 1, and they showed decreased interpretation activity in the early stage in teaching session 2 compared to session 1.

The above results indicated the EG began to show more adaptive decision-making behavior while they gained more experience with the support of technology. Interpreting activities demonstrate how shared understanding evolves, especially at the early stage of problem solving. With the experience gaining from Teaching Session 1, especially with the support of visualization and argumentation tools, shared understandings were built more easily without much deliberate interpretation. Shared understanding helps EG students put more effort on collecting patient data, which further facilitates their management activities in the late stage. That explains why in the late stage of problem solving, the EG tended to have more management than the CG. This pattern of behavior change over time indicates that collaborative tools can facilitate students' development of adaptive decision-making under emergency situation. In contrast, the CG did not show this adaptive pattern. In the late stage of problem solving, they showed a dramatic decrease of patient management in teaching session 2 (2%) compared to teaching session 1 (26%) since more effort and time was put into planning and collecting the patient

information. I suggest that they ran into this impasse because they lacked the support of collaborative tools which can provide alternative opinions and help to build shared understanding of the problem.

Although not significant, EG and CG students communicated more in the early stage (Table 4.8) indicating that they were building shared understandings of the situation to collaborate more effectively in the later stage. In addition, EG students communicated more in Teaching Session 1 than Teaching Session 2 (Table 4.9). The results indicate that EG students tended to build shared understanding through communication in the early sessions. This finding is consistent with Heath's study (1991) on language use by sports teams. At the beginning of the season, team-mates communication interactions were lengthy and explicit. As the season wore on communication interactions shortened and grew cryptic. This suggests that team members had developed shared models of the game and their roles in it so that less communication was needed as a guiding or correcting role.

Decreased communication can also be seen as the result of the increased urgency of patient's situation and difficulty of the task. Kleinman and Serfaty (1989) examined the effects of workload on communication and they found that as workload increased, the amount of communication decreased. They interpreted this as an exercise of mutual mental models that allowed participants to anticipate each other's resource needs and actions.

The findings above imply that in the early stage, EG students communicated in order to construct shared understandings of the problem. Further, their communicative interactions were supported by shared visualization tools. Even though patient information was written on a traditional whiteboard at the front of the class, each EG sub-

group had its own view of the patient's information via their laptops. Furthermore, in the late stage, because the support of the annotations on the interactive whiteboards, shared understanding was facilitated by shared visualizations which reduced the need for informative communication and negotiation for plans. In contrast, in the late stage CG students tended to spend more time interpreting the patient situation because they were still constructing shared understandings of the patient situation. The total time allowed for solving the patient's problem is fixed, too much time spent on interpreting the situation would compromise the time needed for managing the patient.

Most EG student annotations dealt with data collection and patient management, which accounts for why in the later stage, when both EG and CG students ran into difficulty and were unable to come up with management procedures, EG students outperformed CG students. EG student annotations enabled them to discuss patient management procedures.

One purpose of this study was to understand the relationship between decision-making and communicative activities. Unfortunately, perhaps due to low frequencies, there were no statistical differences between the EG and CG student communicative activities. Consequently, it is impossible to correlate differences in decision-making activities to communicative activities. However, in a similar study exploring the relationship between collaborative inquiry and communicative activities. Saab et al. (2005) found that informative and elicitive activities were correlated to collecting and interpreting data so as to build common grounds. Argumentative, elicitive, and responsive activities were correlated to establish common conclusions. This finding implies that irrespective of the communication pattern, the goal of building shared

understandings of the problem state and of the actions to be taken is very important. According to different correlations identified between different collaborative inquiry and communicative activities, different levels of shared understandings are constructed. For example, Saab et al (2005) identified four levels of common ground: (a) constructing common understanding of the problem, (b) reaching the same hypothesis, (c) sharing the same techniques, and (d) establishing the same conclusions. Several aspects of shared understanding have also been identified in this study. In the early stage of problem solving, students communicate in order to understand the patient's situation so as to plan further procedures. Here, shared understandings mainly pertain to the patient's situation. In the late stage, students seek to agree on how to stabilize the patient and shared understandings mainly pertain to managing the patient.

This study found that collaborative tools have an impact on the time needed to develop shared understanding. With the support of visualization and argumentation tools, EG students achieved shared understandings of the patient's situation in the early stage so that in the late stage their communication decreased and their management actions increased. Since shared understandings are constructed based on outside resources from collaborative tools, students might come into conflict but they negotiated and reached agreements. For example, in excerpt 7 in chapter 4, two EG students disagreed on whether to give medication or to wait for X-rays. After arguing, they reached agreement. On the other hand, CG students in conflict tended to reach superficial agreement without negotiation. For example, excerpt 9 in chapter 4 shows two CG students who were not sure about bolusing but they did not elaborate and reach an agreement.

This study used the notion of shared understandings to investigate the relationship between computer-based learning environments (CBLEs), social interaction and collaborative NDM. Qualitative analysis suggests that computer-based visualization tools support collaborative NDM by enhancing communicative interaction (Figure 5.1). Shared visualizations can clarify verbal interaction and promote productive argumentation and negotiation. By comparing discussions among CG students and EG students (refer excerpts 1-7 in Chapter 4), it can be seen that EG student communication is guided by shared annotations which lead to more productive decision-making activities. CG students on the other hand ran out of things to talk about. Shared cognition facilitates the construction of shared situation models and joint problem spaces which lead to better decision making and problem solving. In the following section, the role of collaborative tools will be discussed.

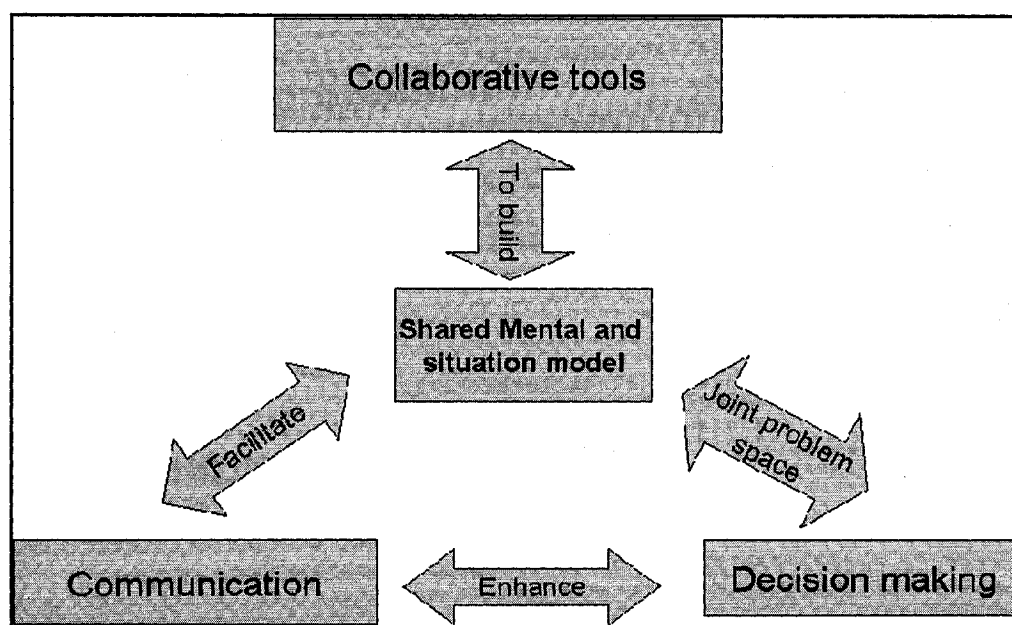


Figure 5.1. Relationship between Collaborative tools, Communication, and Decision making.

5.4 Role of Collaborative Tools

The advancement of information technology provides rich opportunities for complex collaborative learning. Individual or group cognition can be shared using multiple representations of both problem solving domains and communication interactions. Therefore, CBLEs can also be used to understand relations between patterns of communicative interactions and problem solving. This section will discuss how the interactive whiteboard served as different tools that influenced communication and decision making.

5.4.1 Interactive Whiteboards — as a Medium and as Stimuli for Communication

Students did not collaborate spontaneously, even though the teacher encouraged them to do so. Students tended to work alone. This can be seen from the microanalysis of CG students (Excerpt 8 and 9 from Chapter 4). Although it is difficult to show that interactive whiteboards promote productive decision-making, they clearly provide new ways of communicating.

The interactive whiteboard as a digital medium provided EG students with shared visualizations of the patient chart and a way to make and share annotations. Even when the patient chart information recorded on the interactive whiteboard had been erased, students could ‘replay’ them later in the activity. Annotations as external representations by observers provide a foundation for developing shared understanding of the situation. That is, interactive whiteboard representations function as shared memories. EG student decisions were influenced by interactive whiteboard annotations, which served to remind them of previous ideas and possibly stimulated further productive problem solving. For example, observers used their annotations to comment on the activities of other EG

students and to make suggestions. Students' discourse in the later stage was mainly directed by these observations and annotations either from other subgroups or from themselves. EG students also used the interactive whiteboard as a note-taking tool to support future decision making. These interactive whiteboard functions helped EG students to construct shared understandings to support their collaborative decision-making. Student annotations and discourse may be stimulated by the representation of prior ideas, prompting the consideration of earlier discussions that others provided in earlier proposals. It is more difficult to ignore the implications of earlier ideas when one is implicitly aware that one's discourse may also influence the thinking of others (Suthers, 2003a).

5.4.2 Interactive Whiteboard — as Cognitive Tools to Scaffold Communication and Problem Solving

Although the interactive whiteboard was originally designed as a collaborative tool to support collaborative learning, it is also a cognitive tool. Cognitive tools can enhance learning by: (a) supporting cognitive processes, such as memory and metacognition; (b) freeing up cognitive resources for higher level thinking skills by providing support for lower level cognitive processes; (c) providing learners with opportunities for practice in the context of complex simulated real-world problems; (d) allowing learners to generate and test hypotheses in authentic problem solving contexts; and (e) reifying student problem solving through computer traces of their problem solving efforts, such as evidence collection, data representation, interpretation, argumentation, and self-assessment (Jonassen & Reeves, 1996; Lajoie, 2005; Lajoie & Derry, 1993; Salomon, Perkins, & Globerson, 1991). The interactive whiteboard records

patient information on an organized patient chart so that the patient's dynamic situation can be easily recognized. In addition, students can also go back to previous information saved on the interactive whiteboard even if the writing on the traditional whiteboard has been erased. It supports decision making as external memory. Annotations provide alternative opinions and are shared by all group members. Shared annotations facilitate the construction of a shared understanding of the patient and help students put more effort on important cognitive processes such as patient management activity.

Different cognitive processes can be scaffolded by different forms of representations. For example, the interaction can be represented as either free style or structured (Baker & Lund, 1997). Students using free style interaction communicated less but worked more on graphing. In contrast, students using structured interaction representation communicated more to reach agreement and common understanding. Consequently, interactive whiteboard representations are more than simple media for communicating or recording of decisions. Such representations can also stimulate and guide communication and decision-making. Visually structured and constrained representations can guide collaborative learning in ways that plain text cannot (Fischer et al., 2002; Toth, Suthers, & Lesgold, 2002). In this study, interactive whiteboard patient charts are organized so that different kinds of patient information can be recorded and placed in separate columns, e.g., examination, vital signs, management, and annotation. The patient's rapidly deteriorating vital signs stimulate student discourse, which is guided by previously collected information on examination and management procedures.

5.4.3 *Electronic Algorithm — Dropdown Menu*

The emergency algorithm was put into a dropdown menu. It was assumed that the students would use the 'ABCDEF' emergency algorithm more in the early stage than in the later stage of the deteriorating patient activity. However this was not the case. They seldom used the algorithm which may have been due to time limitations. In fact, the students used the algorithm more during the debriefing stage.

One major reason of the limited use of the electronic algorithm could be the high cognitive demand on the task. Under such conditions, the students might not have had time to seek help. Their referencing behavior shows the scanning of each algorithm category was rapid and cursory. In addition, during the role-play stage, the teacher as the nurse and as the patient tried as little as possible to interfere with student decision-making activity. Students did not receive explicit instructions as to how and when they should seek online help. During the debriefing stage, when replaying the case, the teacher explained to students where they should have gone for help when they ran into difficulties during problem solving.

The above finding led to three questions: (a) What can be expected from students by providing them with the electronic algorithm? (b) What kind of representations should an electronic algorithm have? and (c) What can be done to encourage students to use the algorithm more often?

Student referencing behavior suggests that the electronic algorithm might be of limited use in urgent situations. In order to examine the long term effects of the electronic algorithm, we must either extend the length of the decision-making activity so that

students will have more time to use the algorithm, or provide students with explicit instruction on when and how to use it.

The dropdown menu algorithm is the simple version of the text-based algorithm. It provides students with rough ideas as to what kind of problems they should think about when treating the deteriorating patient. Compared to the text-based algorithm (See Appendix 5), it is difficult to fit a great deal of detailed information into a dropdown menu. It is also impossible to provide detailed instruction as to what students should do in a given situation.

Helping students practice using the emergency algorithm and integrating it into their daily activities was a major goal of the 'deteriorating patient' learning activity. It was expected that providing students with an easy-to-use electronic algorithm the student might use this algorithm if they had been given more practice using it, which would facilitate the process of integrating declarative and procedural knowledge.

5.5 Naturalistic Decision-making (NDM)

This study examined NDM in a simulated medical emergency, rather than in the laboratory setting in which diagnostic reasoning, hypothesis generation and knowledge structure were emphasized. The design and methodology used in this study were non-obtrusive, which led to difficulties in so far as results had to be interpreted inferentially, on the basis of observations of the group's management actions, plans, and collected patient data. In traditional laboratory-based medical decision-making studies, subjects are usually asked to do think-aloud protocols which focus on collecting evidence, making diagnoses, and giving explanations (Patel & Arocha, 2000). Direction of reasoning and knowledge structures are identified based on analyses of think-aloud protocols. In NDM

settings, such as a medical emergency, the goal is to stabilize the patient while making a diagnosis. Students managed patients based on their vital signs, situations and information obtained rather than based on certain specific hypotheses.

The collaborative NDM framework refers to shared mental and situation models that are consistent with the theory of 'common ground'. In face-to-face collaborative decision-making situations, people use verbal discourse, gesture, and body language to construct common situational understandings. Mental and situational models include the environment, task and team knowledge (Luczak, Muhlfelder, & Schmidt, 2003). In this study, environmental knowledge encompassed understanding the technology and cognitive tools (Lajoie, 2000; Orasanu, 2005; Salas, Oser, Cannon-Bowers, & Daskarolis-Kring, 2002) designed to support the teaching activity. Team knowledge included shared understanding about team interaction processes, such as sharing information, monitoring each other's activities and solutions, and supporting each other. Members of an effective team provide information without being asked because they know it is needed because they have reflected on shared task understandings (Serfaty, Entin, & Volpe, 1993). This has been called 'cognitive empathy' (Artman & Waern, 1998). Results showed that EG students engaged in more informative interaction in the early stage while CG students engaged in more informative interaction in the later stage. Meanwhile, EG students engaged in other discourse activities in the early stage as well. Compared to CG students, EG students built a shared understanding about the patient situation and the task in the early stage, which enables the team to work more efficiently and effectively. This is consistent with the hypothesis that shared visualization will facilitate communicative interactions and the development of shared understandings.

5.6 Limitations of the Study

The purpose of this study was to examine how the introduction of collaborative technology influences communication and decision-making. CG and the EG students exhibited differences in some of their decision-making activities across the two teaching sessions and different stages. However, there were no significant post-test differences in similar decision making activity. One possible reason could be the small sample size. Another could be due to the nature of the intervention. In order to see permanent changes in decision-making skills, more teaching interventions may be needed so as to enhance the culture of collaborative decision making communities.

Although shared visualization tools were found to support decision making, they did not seem to significantly affect EG student communicative activities. It could be that because emergency medicine requires quick decisions, it attenuates less communication.

The argumentation tools designed in this study are different from other argumentation tools such as Belvedere (Suthers et al., 1995) where different arguments are represented by different symbol systems, and students can create connections between these arguments. Stahl (2005) found connecting textual postings to mathematical graphics facilitated students' collaborative interaction. Annotation tools could have been designed to encourage students to connect their annotations to decision-making information in other columns of the patient chart on the interactive whiteboard representations, but this would have increased both the complexity of the software and the students' cognitive load, which would be inappropriate in time sensitive tasks.

Given that this was a NDM activity, and that this study took the clinical teaching session as the experimental environment, the study was then limited by constraints

inherent to the session: for example, the number of sessions could not be changed, nor could the amount of time per session. The study could only operate within the limits set out by the clinical teaching session. The teaching sessions were one hour long and the actual deteriorating patient activity ran 20 to 30 minutes. The activity was constrained by three factors. The first factor was that the technology introduced both for the teaching and for student collaboration had to be seamless and user friendly. We had planned to use the interactive whiteboard in 'projection mode' and a projector. This would have allowed the teacher to use a stylus as a mouse to transform the traditional whiteboard at the front of the class into a computer screen. However, training in the use of these functions was time consuming and the technology was unstable. Consequently we used the 'whiteboard mode' which works like a traditional whiteboard. However, this rendered the teaching less flexible, e.g., the teacher could not switch to earlier information states. If the 'projection mode' and projector could be used smoothly, the simulation would be more authentic. For example, if the patient had pneumonia, the teacher could retrieve and display X-rays from the server because the whiteboard is connected to a computer. Students would be able to make their own judgments according to their interpretations of the X-rays. The teacher would have more control over the teaching activity. He could also display earlier patient states again instead of relying on the assistance of the researcher to project saved information onto the whiteboard.

The second constraining factor was that the task of using the interactive whiteboard must not be too complicated because of time and cognitive constraints. The students need to solve the problem quickly and technology should both make their job easier and augment their decision-making abilities. To this effect, interactive whiteboard

visualization tools could be imposed by adding connection functions as in the Virtual Math Teams project by Stahl (2005). In Stahl's study students were allowed to make direct connections between their online chatting and mathematical graphing. In a future study observers could highlight relevant decision-making information and connect their annotations to that information. This might help build up tightly woven networks of shared meanings.

The third constraining factor was that due to the NDM environment, the experiment could not be controlled as well as in lab-based settings. For example, students in class who were on call had to answer their pagers even if it was inconvenient for the present study. This led to the problem of subject inconsistency across the two teaching sessions. However, this problem was solved by examining the effects on group levels rather than on individual levels.

5.7 Directions for Future Research

This study examined how students solve medical problems with the support of an interactive whiteboard in a face-to-face classroom setting. As stated in the literature review, collaborative tools can serve as both visualization and argumentation tools, as well as management tools which provide students with advice and dynamic assessment. This study focuses on the visualization and argumentation tools. Future research can examine how management tools can be used to support student decision making.

Medical educators want to know how students construct knowledge and acquire skills and it is now well accepted that schools seek not to turn students into experts, but to foster students transformation into proactive life-long learners given that the acquisition of expertise in any field involves a series of transitions in which instruction and

assessment are crucial (Lajoie, 2003). One of the most successful methods of assessing learning and instruction is dynamic assessment, which, by providing on-line moment-by-moment individualized feedback, fosters highly adaptive learning and instruction (Lajoie & Lesgold, 1992). Individualized feedback is important for the development of metacognitive skills which are emphasized by NDM study (Orasanu & Salas, 1993) but these were not examined in the current study.

Future research can transform the deteriorating patient activity into a simulated patient care system to support collaborative decision making by providing users with dynamic assessment/feedback. To do this, the system must incorporate techniques and reasoning strategies that enable it to maintain a current understanding of student problem solving and decision-making activities (Hawkes & Derry, 1996). Students' understanding of the problem state is represented and shared by visualization tools and they communicate their interpretations and decisions via argumentation tools. Management tools guide students according to their externalized problem representation and communication behaviour based on which students solve the problem collaboratively via networked environments. Therefore, it is important to design management tools that provide students with dynamic/adaptive feedback by contrasting their performance with that of other students which are also demonstrated in the same structured interface. The management tools will remind students when relevant events, such as patient management conflicts or misunderstanding are detected.

To do that, management tools should be able to track and collect each individuals' problem solving and interaction activities (mirroring tools), model desired and actual

cognitive and interaction states of collaborative medical decision-making (metacognitive tools), and provide students analytical results on their performance (advising tools).

The design and development of management tools is complex. It should be based on the understanding of the task (task model), the kinds of knowledge and skills that should be assessed (student model), how experts solve the problem (expert model), and what information can be used to measure knowledge and skills in the student model (evidence model).

Task models are about the kind of tasks or situations that can elicit expected behaviors. The task model is based on the cognitive framework of emergency decision-making developed in this thesis. Cognitive Task Analysis (CTA) can be used to elicit the declarative and procedural domain knowledge needed to model expert decision-making against which student decision-making is assessed. Student models are a series of evolving student problem spaces and knowledge states based on which pedagogical strategies arise. This is consistent with the claim that expertise emerges through a series of transitions (Lajoie, 2003). Student decision-making actions fall into five categories: (a). planning, (b). managing the patient, (c). gathering evidence, (d) forming hypotheses, and (e) interpreting. The evidence models could be structured and assembled into a student model. Planning and managing reveal how students construct and explore problem spaces. Gathering evidence, forming hypotheses and interpreting reveal how student develop and organized their knowledge.

These models, developed based on evidence-centered assessment (Mislevy, Steinberg, Breyer, Almond, & Johnson, 2002) and intelligent feedback on student performance (Lesgold, Lajoie, Logan, & Eggen, 1990) can be used in the development of

simulated patients that represents scenarios in the real world emergency medical care situation. The simulated patient will (a) provide a complementary individualized, adaptive learning environment for students, (b) characterize student problem solving and decision-making in emergency medicine, (c) represent student state of knowledge, (d) compare student-student and student-expert solution paths and provide feedback, and (e) facilitate students' collaborative decision making by getting them to better understand each other's perception of the problem.

5.8 Contributions

This study contributes to methodological, pedagogical, and practical perspectives. It contributes to the methodological perspective in three ways. First, both quantitative and qualitative methods were used to examine differences in decision-making activities, communicative activities, and computer annotation activities. Quantitative methods were used to identify general differences in these activities and qualitative methods were used to explore and describe relationships between these activities and mechanisms of the differences between the groups.

Second, both individual cognition and group cognition were investigated in this study. In the classroom activity group cognition, or socially distributed cognition in naturalistic medical decision making, was focused on. Post tests focused on individual problem solving and decision-making activities. The results showed that collaborative tools had an impact on group cognition but not on individual cognition because there were not enough teaching interventions. This implies that although cognitive tools produce an immediate influence on student cognition, a permanent impact can only be realized after the culture of CSCL environments is established.

Third, the focus shifted from the traditional study of diagnostic reasoning to the study of management reasoning, which more closely corresponds to the work of medical doctors in real world situations.

This study contributes to the pedagogical perspective in its focus on authentic teaching activities which simulated naturalistic decision-making situations, rather than on medical cognition in the laboratory settings. The results better represent real world environments and situations and have more value for both teaching and preparing medical professionals to deal with medical emergencies. For example, providing physicians with collaborative tools that facilitate constructing shared understanding of the situation might enhance their decision-making skills. But since this computer-supported simulation is relatively new to students, some advice should be provided when necessary. For example when the emergency algorithm dropdown menu was not referred to during problem solving as expected, the teacher could have reminded students to refer to the 'ABCDEF' algorithm. A lot of motivation and emotion were involved in the 'deteriorating patient' teaching session. Since students played active and essential roles and realistic situation emotions were involved, a motivated and skilled teacher is important to motivate students to participate and to create a authentic and safe atmosphere.

Finally, the study contributes to a practical perspective in that the, interactive whiteboard can support collaborative problem solving in distributed environments. Future clinical teaching practice can be designed to meet the practical need of providing more clinical teaching sessions to more students. With interactive whiteboard support and networked computers, students from different teaching hospitals can benefit from such

learning activities. This could also help solve problems arising from a lack of resources for clinical teachers in this area.

5.9 Summary

This study investigated the decision-making and communicative activities of two groups participating in a simulated medical emergency: the CG students used a traditional whiteboard and the EG students used a computer-based interactive whiteboard. Significant differences in the decision making activities of the EG and CG students were found. EG students planned less than the CG students possibly because their planning was scaffolded by the collaborative tools and they were able to spend more time and effort on other important issues, such as managing the patient. In the early stage of decision-making, EG students spent more time interpreting the situation and less time managing the patient than the CG students. In the late stage the EG students spent more time managing the patient but less time interpreting the situation. When Teaching Session was taken into consideration, different patterns of 3-way interaction emerged. EG group tended to interpret less in the early stage in session 2 compared to session 1, and CG group tended to manage less in the late stage in session 2 compared to session 1.

The results indicated that in the early stage EG students spent time interpreting aspects of the patient in order to construct shared understanding or to reflect on these aspects of the patient. In the late stage as the patient's situation grew increasingly dire, EG students tended to engage in more management actions in order to stabilize the patient.

Qualitative analysis supports these findings thus further indicating that shared visualizations of the patient charts and shared annotations can clarify and promote

productive argumentation and negotiation. Shared cognition facilitates the construction of shared understandings of situations and of joint problem spaces which lead to better decision making and problem solving. Thus, collaborative tools are effective for promoting collaborative cognition in real world emergencies.

REFERENCE

- Aimeur, E., & Frasson, C. (1996). Analyzing a new learning strategy according to different knowledge levels. *Computers and Education*, 27(2), 115-127.
- Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review*, 89, 369-406.
- Andriessen, J., Baker, M., & Suthers, D. (Eds.). (2003). *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments*. Dordrecht, Netherlands: Kluwer Academic.
- Arkes, H. R., Dawes, R. M., & Christensen, C. (1986). Factors influencing the use of a decision rule in a probabilistic task. *Organizational Behavior & Human Decision Processes*, 37(1), 93-110.
- Arocha, J. F., Patel, V. L., & Patel, Y. C. (1993). Hypothesis generation and the coordination of theory and evidence in novice diagnostic reasoning. *Medical Decision Making*, 13, 198-213.
- Artman, H., & Waern, Y. (1998). Creation and loss of cognitive empathy at an emergency control centre. In Y. Waern (Ed.), *Cooperative process management: Cognition and information technology* (pp. 69-76). London: Taylor & Francis.
- Avouris, N., Dimitracopoulou, A., & Komis, V. (2003). On analysis of collaborative problem solving: An object-oriented approach. *Computers in Human Behavior*, 19(2), 147-167.
- Ayala, G., & Yano, Y. (1998). A collaborative learning environment based on intelligent agents. *Expert Systems with Applications*, 14(1-2), 129-137.

- Azevedo, R. (1997). *Expert problem solving in mammogram interpretation: A visual cognitive task*. Unpublished doctoral dissertation, McGill University, Montreal, Quebec, Canada.
- Azevedo, R., & Lajoie, S. (1998). The cognitive basis for the design of a mammography interpretation tutor. *International Journal of Artificial Intelligence in Education*, 9, 32-44.
- Baker, M. (2003). Computer-mediated argumentative interactions for the co-elaboration of scientific notions. In J. Andriessen, M. Baker & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning* (pp. 47-78). Dordrecht, Netherlands: Kluwer Academic.
- Baker, M., Cohen, J. L., & Moeller, B. (1997, December). *KidCode: Using email to structure interactions for elementary mathematics instruction*. Paper presented at the Second International Conference of Computer-Supported Collaborative Learning, Toronto, Canada.
- Baker, M., de Vries, E., Lund, K., & Quignard, M. (2001, March). *Computer-mediated epistemic interactions for co-constructing scientific notions: Lessons learned from a five-year research program*. Paper presented at the First European Conference on Computer-Supported Collaborative Learning, Maastricht, Netherlands.
- Baker, M., & Lund, K. (1997). Promoting reflective interactions in a CSCL environment. *Journal of Computer Assisted Learning*, 13(3), 175-193.
- Baylor, A. L. (2000). Beyond butlers: intelligent agents as mentors. *Journal of Educational Computing Research*, 22(4), 373-382.

- Baylor, A. L., & Kim, Y. (2003). *Validating pedagogical agent roles: Expert, Motivator, and Mentor*. Paper presented at the Annual World Conference of Educational Multimedia, Hypermedia, & Telecommunication (Ed-Media 2003), Honolulu, Hawaii.
- Beach, L. R., & Lipshitz, R. (1993). Why classical decision theory is an inappropriate standard for evaluating and aiding most human decision making. In G. A. Klein, J. Orasanu, R. Calderwood & C. E. Zsombok (Eds.), *Decision making in action: Models and methods* (pp. 21-35). Westport, CT: Ablex Publishing.
- Brewer, W., & Nakamura, G. (1984). The nature and functions of schemas. In R. Wyer & T. Srull (Eds.), *Handbook of Social cognition* (pp. 119-160). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32-42.
- Camerer, C. F., & Johnson, E. J. (1991). The process-performance paradox in expert judgment: How can experts know so much and predict so badly? In A. Ericsson & J. Smith (Eds.), *Towards a general theory of expertise* (pp. 195-217). New York: Cambridge University Press.
- Cannon-Bowers, J. A., & Salas, E. (Eds.). (1998). *Making decisions under stress: Implications for individual and team training*. Washington, DC: American Psychological Association.
- Cannon-Bowers, J. A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In N. J. J. Castellan (Ed.), *Individual and group decision making* (pp. 221-246). Hillsdale, NJ: Lawrence Erlbaum Associates.

- Chan, T.-W., & Baskin, A. B. (1990). Learning companion systems. In C. Frasson & G. Gauthier (Eds.), *Intelligent tutoring systems: At the crossroad of artificial intelligence and education* (pp. 6-33). New Jersey: Ablex Publishing Corporation.
- Chen, W., & Wasson, B. (2002). An instructional assistant agent for distributed collaborative learning. In S. Cerri, G. Gouarderes; & F. Paraguacu (Eds.), *Intelligent Tutoring Systems: Vol. 2363. Lecture Notes in Computer Science* (pp. 609-618). London, UK: Springer.
- Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, 6(3), 271-315.
- Chi, M. T. H., & Glaser, R. (1985). Problem solving ability. In R. J. Sternberg (Ed.), *Human abilities: An information processing approach* (pp. 227-250). New York: W. H. Freeman and Company.
- Chiu, M. M. (2000). Group problem-solving processes: Social interactions and individual actions. *Journal for the Theory of Social Behaviour*, 30(1), 27-49.
- Chong, S. M. (1998). Models of asynchronous computer conference for collaborative learning in large college class. In C. J. Bonk & K. S. King (Eds.), *Electronic collaborators* (pp. 157-182). Mahwah, NJ: Lawrence Erlbaum Associations.
- Clancey, W. J. (1995). A tutorial on situated learning. In J. Self (Ed.), *Proceedings of the International Conference on Computers and Education* (pp. 49-70). Charlottesville, VA: AACE.
- Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representations*. New York, NY: Cambridge University Press.

Cole, M., & Engestrom, Y. (1993). A cultural-historical approach to distributed cognition.

In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 1-46). Cambridge, UK: Cambridge University Press.

Constantino-Conzalez, M., & Suthers, D. (2001). Coaching collaboration by comparing solutions and tracking participants. In P. Dillenbourg, A. Eurelings & K.

Hakkarainen (Eds.), *European perspectives on Computer-supported collaborative learning: First European Conference on Computer-Supported Collaborative Learning (Euro-CSCL)* (pp. 173-180): McLuhan Institute: University of Maastricht.

Cooper, R., & Fox, J. (1997). Learning to make decisions under uncertainty: The contribution of qualitative reasoning. In M. G. Shafto & P. Langley (Eds.), *Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society* (pp. 125-130). Mahwah, NJ: Lawrence Erlbaum Associations.

Custers, E. J., Boshuizen, H. P., & Schmidt, H. G. (1998). The role of illness scripts in the development of medical diagnostic expertise: Results from an interview study. *Cognition and Instruction*, 16(4), 367-398.

Diehl, C. L. (2000, April). *"Reasoner's Workbench" program supports students' individual and collaborative argumentation*. Paper presented at the annual meeting of the National Association for Research and Science Teaching, New Orleans, LA.

Dillenbourg, P., & Self, J. (1992). People power: a human-computer collaborative learning system. In C. Frasson & G. McCalla (Eds.), *The 2nd International*

- Conference of Intelligent Tutoring Systems, Lecture Notes in Computer Science* (pp. 651-660). Berlin, Germany: Springer-Verlag.
- Dimitracopoulou, A. (2005, June). *Designing collaborative learning systems: current trends and future research agenda*. Paper presented at the conference of Computer Supported Collaborative Learning, Taipei, Taiwan.
- Edelson, D., & O'Neill, D. K. (1994, June). *The CoVis collaboratory notebook: Supporting collaborative scientific enquiry*. Paper presented at the Annual National Educational Computing Conference, Boston, Massachusetts.
- Elstein, A., S. (2001). Naturalistic decision making and clinical judgment. *Journal of Behavioral Decision Making*, 14(5), 363-365.
- Elstein, A., Shulman, L., & Sprafka, S. (1978). *Medical problem solving: An analysis of clinical reasoning*. Cambridge, MA: Harvard University Press.
- Elstein, A. S. (1999). Heuristics and biases: Selected errors in clinical reasoning. *Academic Medicine*, 74(7), 791-794.
- Elstein, A. S., & Schwarz, A. (2002). Clinical problem solving and diagnostic decision making: Selective review of the cognitive literature. *British Medical Journal*, 324(7339), 729-732.
- Enyedy, N. (2003). Knowledge construction and collective practice: At the intersection of learning, talk, and social configurations in a computer-mediated mathematics classroom. *Journal of the Learning Sciences*, 12(3), 361-407.
- Feltovich, P. J., Johnson, P. E., Moller, J. H., & Swanson, D. B. (1984). LCS: The role and development of medical knowledge in diagnostic expertise. In W. J. Clancey

- & E. H. Shortliff (Eds.), *Readings in medical artificial intelligence* (pp. 275-319). Reading, MA: Addison-Wesley.
- Feltovich, P. J., Spiro, R. J., & Coulson, R. L. (1995). Learning, teaching, and testing for complex conceptual understanding. In N. Frederiksen, R. J. Missevey & I. I. Bejar (Eds.), *Test theory for a new generation of tests* (pp. 181-217). Hillsdale, NJ: Erlbaum.
- Fischer, F., Bruhn, J., Grasel, C., & Mandl, H. (2002). Fostering collaborative knowledge construction with visualization tools. *Learning and Instruction*, 12(2), 213-232.
- Frederiksen, C. H. (1999). Learning to reason through discourse in a problem-based learning group. *Discourse Processes*, 27(2), 135-160.
- Gaba, D. (1992). Dynamic decision-making in anesthesiology: Cognitive models and training approaches. In D. A. Evans & V. L. Patel (Eds.), *Advanced models of cognition for medical training and practice* (pp. 123-148). Heidelberg, Germany: Springer-Verlag.
- Gaba, D. (1996). Simulator training in anesthesia. In C. Lake (Ed.), *Advances in Anesthesia* (pp. 55-94). St. Louis, MO: Mosby.
- Gaba, D. (1999). The human work environment and anesthesia simulators. In R. Miller (Ed.), *Anesthesia* (5th ed., pp. 2613-2668). New York: Churchill Livingstone.
- Gaba, D. M., Howard, S. K., Fish, K. J., Smith, B. E., & Sowb, Y. A. (2001). Simulation-based training in anesthesia crisis resource management (ACRM): A decade of experience. *Simulation Gaming*, 32(2), 175-193.
- Glaser, R., & Chi, M. T. H. (1988). Overview. In M. T. H. Chi & R. Glaser (Eds.), *The nature of expertise* (pp. xv-xxviii). Hillsdale, NJ: Lawrence Erlbaum Associates.

- Gomez, L. M., Fishman, B. J., & Pea, R. D. (1998). The CoVis Project: Building a large scale science education testbed. *Interactive Learning Environments*, 6(1-2), 59-92.
- Goodman, B., Soller, A., Linton, F., & Gaimari, R. (1998). *Encouraging student reflection and articulation using a learning companion*. Paper presented at the 8th World Conference on Artificial Intelligence in Education (AI-ED 98), Kobe, Japan.
- Graesser, A. C., Moreno, K. N., Marineau, J. C., Adcock, A., Olney, A., & Person, N. (2003). *AutoTutor Improves Deep Learning of Computer Literacy: Is It the Dialog or the Talking Head?* Paper presented at the International Conference of Artificial Intelligence in Education, Sydney, Australia.
- Greeno, J. (1998a). The situativity of knowing, learning, and research. *American Psychologist*, 53(1), 5-26.
- Greeno, J. G. (1998b). The Situativity of Knowing, Learning, and Research. *American Psychologist*, 53(1), 5-26.
- Guzdial, M., & Turns, J. (2000). Effective discussion through a computer-mediated anchored forum. *Journal of the Learning Sciences*, 9(4), 437-469.
- Hall, R., Koschmann, T., & Miyake, N. (Eds.). (2002). *CSCCL 2, Carrying Forward the Conversation*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Hawkes, L. W., & Derry, S. J. (1996). Advances in local student modeling using informal fuzzy reasoning. *International Journal of Human-Computer Studies*, 45(6), 697-722.

- Hayes, J. R., & Flower, L. (1980). Identifying the organization of writing processes. In L. Gregg & E. Steinberg (Eds.), *Cognitive processes in writing: An interdisciplinary approach*. Hillsdale, NJ: Lawrence Erlbaum.
- Heath, S. B. (1991). "It's about winning!" The language of knowledge in baseball. In L. B. Resnick, J. M. Levine & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 101-124). Washington, DC: American Psychological Association.
- Heller, R. F., Saltzstein, H. D., & Caspe, W. B. (1992). Heuristics in medical and non-medical decision-making. *Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, 44A(2), 211-235.
- Hirsch, L., Saeedi, M., Cornillon, J., & Litosseliti, L. (2004). A structured dialogue tool for argumentative learning. *Journal of Computer Assisted Learning*, 20(1), 72-80.
- Hmelo-Silver, C. E. (2003, January). *Facilitating collaborative knowledge construction*. Paper presented at the 36th annual Hawaii International Conference on System Sciences, Big Island, Hawaii.
- Hmelo, C. E. (2002). Collaborative ways of knowing: Issues in facilitation. In G. Stahl (Ed.), *International Conference on Computer-Supported Collaborative Learning* (pp. 199-208). Hillsdale, NJ: Lawrence Erlbaum Association.
- Hmelo, C. E. (2003, January). *Facilitating collaborative knowledge construction*. Paper presented at the 36th annual Hawaii International Conference on System Sciences, Big Island, Hawaii.
- Hoadley, C. M., & Linn, M. C. (2000). Teaching science through online, peer discussions: SpeakEasy in the knowledge integration environment. *International Journal of Science Education*, 22(8), 839-857.

- Hogan, K., Nastasi, B. K., & Pressley, M. (1999). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction, 17*(4), 379-432.
- Hron, A., & Friedrich, H. F. (2003). A review of web-based collaborative learning: Factors beyond technology. *Journal of Computer Assisted Learning, 19*(1), 70-79.
- Hron, A., Hesse, F. W., Cress, U., & Giovis, C. (2000). Implicit and explicit dialogue structuring in virtual learning groups. *British Journal of Educational Psychology, 70*(1), 53-64.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT press.
- Hutchins, E., & Klausen, T. (1996). Distributed cognition in an airline cockpit. In Y. Engestr & D. Middleton (Eds.), *Cognition and communication at work* (pp. 15-34). New York, NY: Cambridge University Press.
- Jermann, P. (2004). *Computer support for interaction regulation in collaborative problem-solving*. University of Geneva.
- Jermann, P., & Dillenbourg, P. (2003). Elaborating new arguments through a CSCL script. In J. Andriessen, M. Baker & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 205-226). Dordrecht, Netherlands: Kluwer Academic.
- Jermann, P., Soller, A., & Muehlenbrock, M. (2001, March). *From mirroring to guiding: A review of state of the art technology for supporting collaborative learning*. Paper presented at the First European conference on Computer-supported collaborative learning, Maastricht, Netherlands.

- Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research*: (1989).
- Johnson, D. W., & Johnson, R. T. (Eds.). (1999). *Learning together and alone: Cooperative, competitive, and individualistic learning* (5th ed.). Boston, MA: Allyn & Bacon.
- Johnson, P. E., Duran, A. S., Hassebrock, F., Moller, J., Prietula, M., Feltovich, R. J., et al. (1981). Expertise and error in diagnostic reasoning. *Cognitive Science*, 5, 235-283.
- Johnson, W. L., Rickel, J. W., & Lester, J. C. (2000). Animated pedagogical agents: face-to-face interaction in interactive learning environments. *International Journal of Artificial Intelligence in Education*, 11, 47-78.
- Jonassen, D. H. (1991). Context is everything. *Educational Technology*, 31(6), 35-37.
- Jonassen, D. H. (1994). Toward a constructivist design model. *Educational Technology*, 34(4), 34-37.
- Jonassen, D. H. (2000). *Computers as mindtools for school: Engaging critical thinking*. Upper Saddle River, N.J: Merrill.
- Jonassen, D. H., & Carr, C. (2000). Mindtools: Affording multiple knowledge representations for learning. In S. P. Lajoie (Ed.), *Computers as cognitive tools II: No more walls: Theory change, paradigm shifts and their influence on the use of computers for instructional purposes* (pp. 165-196). Mahwah, NJ: Lawrence Erlbaum Associates.

- Jonassen, D. H., & Reeves, T. C. (1996). Learning with technology: Using computers as cognitive tools. In D. H. Jonassen (Ed.), *Handbook of Research for Educational Communications and Technology* (pp. 693-719). New York: Simon and Schuster.
- Joseph, G. M., & Patel, V. L. (1990). Domain knowledge and hypothesis generation in diagnostic reasoning. *Medical Decision Making*, 10(1), 31-46.
- King, A. (1999). Discourse patterns for mediating peer learning. In A. M. O'Donnell & A. King (Eds.), *Cognitive perspectives on peer learning* (pp. 87-115). Mahwah, NJ: Lawrence Erlbaum Associations.
- Klein, G., Calderwood, R., & Clinton-Cirocco, A. (1986, October). *Rapid decision making on the fire ground*. Paper presented at the 30th annual meeting of the Human Factors and Ergonomics Society, Santa Monica, CA.
- Klein, G. A. (1993). A recognition-primed decision (RPD) model of rapid decision making. In G. A. Klein, J. Orasanu, R. Calderwood & C. E. Zsombok (Eds.), *Decision making in action: Models and methods*. (pp. 138-147). Norwood, NJ: Ablex Publishing.
- Klein, G. A., Orasanu, J., Calderwood, R., & Zsombok, C. E. (1993). *Decision making in action: Models and methods*. Norwood, NJ: Ablex Publishing.
- Kleinman, D. L., & Serfaty, D. (1989, April). *Team performance assessment in distributed decision making*. Paper presented at the first conference of Interactive Networked Simulation for Training, Orlando, FL.
- Kreijns, K., Kirschner, P. A., & Jochems, W. (2002). The sociability of computer-supported collaborative learning environments. *Educational Technology & Society*, 5(1), 8-22.

- Kumpulainen, K., & Kaartinen, S. (2003). The interpersonal dynamics of collaborative reasoning in peer interactive dyads. *Journal of Experimental Education*, 71(4), 333-370.
- Kushniruk, A. W., Patel, V. L., & Marley, A. A. (1998). Small worlds and medical expertise: Implications for medical cognition and knowledge engineering. *International Journal of Medical Informatics*, 49(3), 255-271.
- Lajoie, S. (2005). Cognitive tools for the mind: The promises of technology: Cognitive amplifiers or bionic prosthetics? In R. J. Sternberg & D. Preiss (Eds.), *Intelligence and technology: Impact of tools on the nature and development of human skills* (pp. 87-102). Mahwah, NJ: Erlbaum.
- Lajoie, S., & Derry, S. (Eds.). (1993). *Computers as Cognitive Tools*. Hillsdale, NJ: Erlbaum.
- Lajoie, S. P. (1991). A framework for authentic assessment for mathematics. *Education Reserach Review*, 1(1), 6-12.
- Lajoie, S. P. (1993). Computer environments as cognitive tools for enhancing learning. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as Cognitive Tools* (pp. 261-288). Hillsdale, NJ: Erlbaum.
- Lajoie, S. P. (2003). Transitions and trajectories for studies of expertise. *Educational Researcher*, 32(8), 21-25.
- Lajoie, S. P. (Ed.). (2000). *Computer as cognitive tools: No more walls*. Mahwah, NJ: Lawrence Erlbaum Ass.

- Lajoie, S. P., & Azevedo, R. (2000). Cognitive tools for medical informatics. In S. P. Lajoie (Ed.), *Computers as cognitive tools: No more walls* (pp. 247-271). Mahwah, NJ: Lawrence Erlbaum Associates.
- Lajoie, S. P., & Azevedo, R. (in press). Teaching and learning in technology-rich environments. In P. Winne & P. Alexander (Eds.), *Handbook of Educational Psychology* (2nd ed.). Mahwah, NJ: Erlbaum.
- Lajoie, S. P., Azevedo, R., & Fleiszer, D. M. (1998). Cognitive tools for assessment and learning in a high Information flow environment. *Journal of Educational Computing Research*, 18(3), 205-235.
- Lajoie, S. P., Garcia, B. C., Berdugo, G. C., Marquez, L., Espíndola, S., & Nakamura, C. (2006). The creation of virtual and face-to-face learning communities: An international collaborative experience. *Journal of Educational Computing Research*, 35(2), 163-180.
- Lajoie, S. P., Greer, J. E., Munsie, S. D., Wilkie, T. V., Guerrero, C., & Aleong, P. (1995). *Establishing an argumentation environment to foster scientific reasoning with Bio-World*. Paper presented at the International Conference on Computers in Education, Charlottesville, VA.
- Lajoie, S. P., Lavigne, N. C., Guerrero, C., & Munsie, S. D. (2001). Constructing knowledge in the context of BioWorld. *Instructional Science*, 29(2), 155-186.
- Lajoie, S. P., & Lesgold, A. M. (1992). Dynamic assessment of proficiency for solving procedural knowledge tasks. *Educational Psychologist*, 27(3), 365-384.
- Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, 11(11), 65-99.

- Lave, J. (1991). Situated learning in communities of practice. In L. B. Resnick, J. M. Levine & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 63-82). Washington, DC: American Psychological Association.
- Lave, J., & Wenger, E. (Eds.). (1991). *Situated learning: legitimate peripheral participation*. Cambridge, England: Cambridge University Press.
- Lemke, J. L. (1997). Cognition, context and learning: A social semiotic perspective. In D. Kirshner & J. A. Whitson (Eds.), *Situated cognition: Social, semiotic, and psychological perspectives*. (pp. 37-56). Mahwah, NJ: Lawrence Erlbaum Associations.
- Leprohon, J., & Patel, V. L. (1995). Decision-making strategies for telephone triage in emergency medical services. *Medical Decision Making*, 15(3), 240-253.
- Lesgold, A. (1988). Problem solving. In R. Sternberg & E. Smith (Eds.), *The psychology of human thought* (pp. 188-213). Cambridge, NY: Cambridge University Press.
- Lesgold, A., Lajoie, S. P., Logan, D., & Eggan, G. (1990). Applying cognitive task analysis and research methods to assessment. In N. Frederiksen, R. Glaser, A. Lesgold & M. G. Shafto (Eds.), *Diagnostic monitoring of skills and knowledge acquisition* (pp. 325-350). Hillsdale, NJ: Lawrence Erlbaum Associations.
- Lesgold, A., Rubinson, H., Feltovich, P., Glaser, R., Klopfer, D., & Wang, Y. (1988). Expertise in a complex skill: Diagnosing X-ray picture. In M. Chi, R. Glaser & M. J. Farr (Eds.), *The nature of expertise* (pp. 311-342). Hillsdale, NJ: Lawrence Erlbaum Associations.

- Levin, J., Haesun, K., & Riel, M. (1990). Analyzing instructional interactions on electronic mail networks. In L. M. Harasim (Ed.), *Online education: Perspectives on a new environment* (pp. 185-213). New York, NY: Praeger Publishing.
- Lingnau, A., Hoppe, H. U., & Mannhaupt, G. (2003). Computer supported collaborative writing in an early learning classroom. *Journal of Computer Assisted Learning*, 19(2), 186-194.
- Lu, J., & Lajoie, S. P. (2005, June). *Facilitating medical decision making with collaborative tools*. Paper presented at the World Conference on Education Multimedia, Hypermedia & Telecommunications, Montreal, Canada.
- Luczak, H., Muhlfelder, M., & Schmidt, L. (2003). Group task analysis and design of computer-supported cooperative work. In E. Hollnagel (Ed.), *Handbook of Cognitive Task Design* (pp. 99-127). Mahwah, NJ: Lawrence Erlbaum Associations.
- Markman, A. B. (1999). *Knowledge representation*. Mahwah, NJ: Lawrence Erlbaum Associations.
- Mislevy, R. J., Steinberg, L. S., Breyer, F. J., Almond, R. G., & Johnson, L. (2002). Making sense of data from complex assessments. *Applied Measurement in Education*, 15(4), 363-389.
- Neuwirth, C. M., Kaufer, D. S., Chandhok, R., & Morris, J. H. (2001). Computer support for distributed collaborative writing: A coordination science perspective. In G. M. Olson & T. W. Malone (Eds.), *Coordination theory and collaboration technology*. (pp. 535-557). Mahwah, NJ: Lawrence Erlbaum Associates.

- Neuwirth, C. M., & Wojahn, P. G. (1996). Learning to write: Computer support for a cooperative process. In T. Koschmann (Ed.), *CSCAL: Theory and practice of an emerging paradigm Computers, cognition, and work* (pp. 147-170). Mahwah, NJ: Lawrence Erlbaum Associates.
- Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.
- Okada, T., & Simon, H. A. (1997). Collaborative discovery in a scientific domain. *Cognitive Science*, 21(2), 109-146.
- Orasanu, J. (2005). Crew collaboration in space: A naturalistic decision-making perspective. *Aviation, Space, and Environmental Medicine*, 76(6 (Sect2,Suppl)), B154-B163.
- Orasanu, J., & Connolly, T. (1993). The reinvention of decision making. In G. A. Klein, J. Orasanu, R. Calderwood & C. E. Zsombok (Eds.), *Decision making in action: Models and methods* (pp. 3-20). Norwood, NJ: Ablex Publishing.
- Orasanu, J., & Salas, E. (1993). Team decision making in complex environments. In G. A. Klein, J. Orasanu, R. Calderwood & C. E. Zsombok (Eds.), *Decision making in action: Models and methods* (pp. 327-345). Norwood, NJ: Ablex Publishing.
- Paolucci, M., Suthers, D., & Weiner, A. (1996, June). *Automated advice-giving strategies for scientific inquiry*. Paper presented at the Third International Conference on Intelligent Tutoring Systems, Montreal, Canada.
- Patel, V. L., & Arocha, J. F. (2000). The nature of constraints on collaborative decision making in health care settings. In G. Klein (Ed.), *Expertise and naturalistic decision making* (pp. 78-91). Mahwah, NJ: Lawrence Erlbaum Associates.

- Patel, V. L., Arocha, J. F., & Kaufman, D. R. (1994). Diagnostic reasoning and medical expertise. In D. L. Medin (Ed.), *The psychology of learning and motivation: Vol. 31. Advances in research and theory* (pp. 187-252). San Diego, CA: Academic Press.
- Patel, V. L., & Groen, G. J. (1986). Knowledge based solution strategies in medical reasoning. *Cognitive Science*, 10(1), 91-116.
- Patel, V. L., & Groen, G. J. (1991). The general and specific nature of medical expertise: A critical look. In K. A. Ericsson & S. Jacqui (Eds.), *Toward a general theory of expertise: Prospects and limits*. (pp. 93-125). New York, NY: Cambridge University Press.
- Patel, V. L., Groen, G. J., & Arocha, J. F. (1990). Medical expertise as a function of task difficulty. *Memory & Cognition*, 18(4), 394-406.
- Pea, R., Edelson, D., & Gomez, L. (1994, June). *The CoVis Collaboratory: High school science learning supported by a broadband educational network with scientific visualization, videoconferencing, and collaborative computing*. Paper presented at the annual meeting of American Education Research Association, New Orleans, LA.
- Pea, R. D. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed Cognitions: Psychological and educational considerations* (pp. 1-46). Cambridge, UK: Cambridge University Press.
- Pretz, J. E., Naples, A. J., & Sternberg, R. J. (2003). Recognizing, defining, and representing problems. In J. E. Davidson & R. J. Sternberg (Eds.), *The*

- Psychology of problem solving* (pp. 3-30). Cambridge, UK: Cambridge University Press.
- Reimann, P. (2003, July). *How to support groups in learning: More than problem solving*. Paper presented at the 11th International Conference on Artificial Intelligence in Education, Sydney, Australia.
- Resnick, L., Levine, J., & Teasley, S. (Eds.). (1991). *Perspectives on socially shared cognition*. Washington DC: APA Press.
- Roschelle, J., & Pea, R. (1999). Trajectories from today's WWW to a powerful educational infrastructure. *Educational Researcher*, 28(5), 22-25. + 43.
- Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. E. O'Malley (Ed.), *Computer-supported collaborative learning* (pp. 69-97). New York: Springer-Verlag.
- Saab, N., van Joolingen, W. R., & van Hout-Wolters, B. H. (2005). Communication in collaborative discovery learning. *British Journal of Educational Psychology*, 75(4), 603-621.
- Salas, E., Oser, R. L., Cannon-Bowers, J. A., & Daskarolis-Kring, E. (2002). Team training in virtual environments: An event-based approach. In K. M. Stanney (Ed.), *Handbook of virtual environments: Design, implementation, and applications. Human factors and ergonomics* (pp. 873-892). Mahwah, NJ, US: Lawrence Erlbaum Associates.
- Salomon, G. (1993a). Editor's introduction. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. xi-xxi). New York, NY: Cambridge University Press.

- Salomon, G. (1993b). No distribution without individuals' cognition: A dynamic interactional view. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 111-138). New York, NY: Cambridge University Press.
- Salomon, G. (Ed.). (1993c). *Distributed cognition: psychological and educational considerations*. New York, NY: Cambridge University Press.
- Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher*, 20(3), 2-9.
- Scardamalia, M., & Bereiter, C. (1996). Computer support for knowledge-building communities. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm: Vol. 1. Computers, cognition, and work*. (pp. 249-268). Mahwah, NJ: Lawrence Erlbaum Associates.
- Scardamalia, M., & Bereiter, C. (1999). Schools as knowledge-building organizations. In D. P. Keating & C. Hertzman (Eds.), *Developmental health and the wealth of nations: Social, biological, and educational dynamics* (pp. 274-289). New York: Guilford.
- Schmidt, H. G., & Boushuizen, H. P. A. (1993). On acquiring expertise in medicine. *Educational psychology Review*, 5, 205-221.
- Schmidt, H. G., Dauphinee, W. D., & Patel, V. L. (1987). Comparing the effects of problem-based and conventional curricula in an international sample. *Journal of Medical Education*, 62(4), Apr 1987.

- Schoenfeld, A. H., Smith, J. P., & Arcavi, A. (1993). Learning: The microgenetic analysis of one student's evolving understanding of a complex subject matter domain. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 4, pp. 55-175). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Schwartz, A. S. E. A. (2000). Clinical reasoning in medicine. In H. J. J. Mark (Ed.), *Methods in the study of clinical reasoning* (2nd ed., pp. 95-106): Butterworth heinemann.
- Serfaty, D., Entin, E., & Volpe, C. E. (1993, October). *Adaptation to stress in team decision making and coordination*. Paper presented at the Human Factors and Ergonomics Society 37th Annual Meeting, Seattle, WA.
- Shute, V. J., Lajoie, S. P., & Gluck, K. A. (2000). Individualized and group approaches to training. In S. Tobias & J. D. Fletcher (Eds.), *Training and retraining: A handbook for business, industry, government, and the military* (pp. 171-207). New York, NY: Macmillan.
- Simon, H. A., & Associates. (1986). Decision making and problem solving. Retrieved Dec. 13th, 2006, from <http://dieoff.org/page163.htm>
- Sinnott, J. D. (1989). A model for solution of ill-structured problems: Implications for everyday and abstract problem solving. In J. D. Sinnott (Ed.), *Everyday problem solving: Theory and applications* (pp. 72-99). New York, NY: Praeger Publishers.
- Sisson, J. C., Donnelly, M. B., Hess, G. E., & Woolliscroft, J. O. (1991). The characterization of early diagnostic hypotheses generated by physician (experts) and students (novices) at one medical school. *Academic Medicine*, 66, 607-612.

- Slavin, R. E. (1995). *Cooperative learning: Theory, research and practice* (2nd edition ed.). Needham Heights, MA: Allyn & Bacon.
- Soller, A., & Lesgold, A. (2003, July). *A computational approach to analyzing online knowledge sharing interaction*. Paper presented at the 11th international Conference of Artificial Intelligence in Education, Sydney, Australia.
- Soller, A., Martinez, A., Jermann, P., & Muehlenbrock, M. (2005). From mirroring to guiding: A review of state of the art technology for supporting collaborative learning. *International Journal of Artificial Intelligence in Education*, 15(4), 261-290.
- Stahl, G. (2005, December). *Group cognition in chat: Methods of interaction/Methodologies of analysis*. Paper presented at the Nordic Analysis of Interaction and Learning, Gothenburg, Sweden.
- Sternberg, R. J., & Preiss, D. (Eds.). (2005). *Intelligence and technology: Impact of tools on the nature and development of human skills*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Stoyanova, N., & Kommers, P. (2001, March). *Learning effectiveness of concept mapping in a computer supported collaborative problem solving design*. Paper presented at the First European International Conference on Computer-Supported Collaborative Learning, Maastricht, the Netherlands.
- Stoyanova, N., & Kommers, P. (2002). Concept mapping as a medium of shared cognition in computer-supported collaborative problem solving. *Journal of Interactive Learning Research*, 13(1-2), 111-133.

- Suthers, D. (1998, April). *Representations for scaffolding collaborative inquiry on ill-structured problems*. Paper presented at the conference of American Educational Research Association, San Diego, CA.
- Suthers, D. (2003a). Representational guidance for collaborative inquiry. In J. Andriessen, M. Baker & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 27-44). Dordrecht, the Netherlands: Kluwer.
- Suthers, D. (2003b). Representational Guidance for Collaborative Learning. In H. U. Hoppe, F. Verdejo & J. Kay (Eds.), *11th international Conference of Artificial Intelligence in Education* (pp. 3-10). Amsterdam: IOS Press.
- Suthers, D., Connelly, J., Lesgold, A., Paolucci, M., Toth, E., Toth, J., & Weiner, A. (2001). Representational and advisory guidance for students learning scientific inquiry. In K. D. Forbus & P. J. Feltovich (Eds.), *Smart machines in education: The coming revolution in educational technology*. (pp. 7-36). Menlo Park, CA: AAAI/Mit Press.
- Suthers, D., & Hundhausen, C. (2001, March). *Learning by constructing collaborative representations: An empirical comparison of three alternatives*. Paper presented at the First European Conference on Computer-Supported Collaborative Learning, Maastricht, Netherlands.
- Suthers, D., Toth, E., & Weiner, A. (1997, December). *An integrated approach to implementing collaborative inquiry in the classroom*. Paper presented at the Second International Conference on Computer-Support Collaborative Learning, Toronto, Canada.

- Suthers, D., Weiner, A., Connelly, J., & Paolucci, M. (1995, July). *Belvedere: Engaging students in critical discussion of science and public policy issues*. Paper presented at the 7th World Conference on Artificial Intelligence in Education, Washington DC.
- Suthers, D. D. (1999, December). *Effects of alternate representations of evidential relations on collaborative learning discourse*. Paper presented at the Third International Conference on Computer Supported Collaborative Learning, Stanford, CA.
- Suthers, D. D., & Hundhausen, C. D. (2003). An experimental study of the effects of representational guidance on collaborative learning processes. *Journal of the Learning Sciences*, 12(2), 183-218.
- Teasley, S. D., & Roschelle, J. (1993). Constructing a joint problem space: The computer as a tool for sharing knowledge. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as Cognitive Tools* (pp. 229-258). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). Mapping to know: The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education*, 86(2), 264-286.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185(4157), 1124-1131.
- Uresti, R. (2000, June). *Should I teach my computer peer? Some issues in teaching a learning companion*. Paper presented at the Intelligent Tutoring System, Montreal, Canada.

- Vahey, P., Enyedy, N., & Gifford, B. (2000). Learning probability using a collaborative, inquiry-based simulation environment. *Journal of Interactive Learning Research*, 11(1), 51-84.
- van Boxtel, C. (2000). *Collaborative concept learning: Collaborative learning tasks, student interaction, and the learning of physics concepts*. Unpublished Doctoral thesis, Utrecht University, Utrecht, The Netherlands.
- van Boxtel, C., van der Linden, J., & Kanselaar, G. (2000). Collaborative learning tasks and the elaboration of conceptual knowledge. *Learning and Instruction*, 10(4), 311-330.
- van Boxtel, C., & Veerman, A. (2001). *Diagram-mediated collaborative learning: Diagrams as tools to provoke and support elaboration and argumentation*. Paper presented at the first European Conference on Computer-Supported Collaborative Learning, Maastricht, Netherlands.
- van Bruggen, J. M., Kirschner, P. A., & Jochems, W. (2002). External representation of argumentation in CSCL and the management of cognitive load. *Learning and Instruction*, 12(1), 121-138.
- van Dijk, T. A. (1981). Episodes as units of discourse analysis. In D. Tannen (Ed.), *Analyzing discourse: Text and talk* (pp. 177-195). Georgetown: Georgetown University Press.
- Vizcaino, A., Contreras, J., Favela, J., & Prieto, M. (2000, June). *An adaptive, collaborative environment to develop good habits in programming*. Paper presented at the 5th International conference on Intelligent Tutoring Systems, Montreal, Canada.

- Voss, J. F., & Post, T. A. (1988). On the solving of ill-structured problems. In M. T. H. Chi, R. Glaser & M. J. Farr (Eds.), *The nature of expertise* (pp. 261-285). Hillsdale, NJ, England: Lawrence Erlbaum Associates.
- Winne, P. H. (2006). How software technologies can improve research on learning and bolster school reform. *Educational Psychologist*, 41(1), 5-17.
- Wooldridge, M., & Jennings, N. R. (1995). Agent theories, architectures, and languages: A survey. In M. Wooldridge & N. R. Jennings (Eds.), *Intelligent Agents (lecture Notes in Artificial Intelligence)* (Vol. 890, pp. 1-21). Berlin: Springer-Verlag.
- Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting Understanding of Chemical Representations: Students' Use of a Visualization Tool in the Classroom. *Journal of Research in Science Teaching*, 38(7), 821-842.
- Xiao, Y. (2005). Artifacts and collaborative work in healthcare: methodological, theoretical, and technological implications of the tangible. *Journal of Biomedical Informatics*, 38(1), 26-33.
- Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science*, 21(2), 179-217.
- Zhang, J. (2002). Representations of health concepts: a cognitive perspective. *Journal of Biomedical Informatics*, 35(1), 17-24.
- Zsombok, C. E. (1997). Naturalistic decision making: Where are we now? In C. E. Zsombok & G. Klein (Eds.), *Naturalistic decision making* (pp. 3-16). Mahwah, NJ: Lawrence Erlbaum Associates.

Appendix 1: An example of interactive board annotation.

An excerpt from teaching session 1 of EG group that exemplified the effects of DMA on Annotation

Classroom transcription (Interaction between the teacher and SG1: M and P are the two students belong to SG 1, J is the teacher)	Annotation by SG2
M: Yeah, let's put him on oxygen. His O2 SAT is 95 percent, but his blood pressure is low and his heart beat is low. High, sorry, his heart rate is high. (laughing) He is tachycardiac, so we..	
P: Yeah.	
M: O2 for start?	
P: Yeah.	
J: So you start treatment right away with oxygen.	
M: Yes.	
J: How much oxygen? Doctor.	
M: He's sounding at 95 percent for starters. Let's start with... (Pause & Laughter)	
P: Nasal prongs.	
M: No, we give it by mask. The nasal prongs, he is (20:56 cam)	'2 liter'
J: Would it help if I told you he also had a chronic lymphosemic leukemia?	
(General Laughter)	
P: Nasal prongs.	'nasa'
M: By mask. If he's sick. The nurse says he's sick. Mind you his SAT is OK, 95,	
P: Yeah,	erased "2 liter
M: (Maybe) nasal prongs.	nasa"
P: Yeah, sure.	
J: Nasal prongs,	
M: 5 liters.	put back '? 2
J: 5 liters per minute. Anything else that you would do doctor?	liters prongs'
	again

Appendix 2: Instruction for the interview

In this interview, you are going to watch a 10 minutes video clip which is taken from previous clinical teaching of “deteriorating patient”. After watching the video, you are asked to think aloud based on the following issues if **you are referred as the senior doctor**:

- Summary of the case:
 - List the problems (positive evidence)
 - The most important issues that needed to be attended right now
 - List the possible reasons for the most emergent issues
 - If you were the role-play doctor in the video, what will you do differently?
- What you are going to do next:
 - What further questions you are going to ask?
 - What results you are expecting to get?
 - What management you will do to stabilize the patient?
- Hypothesis and justification:
 - List the diagnosis or hypothesis of this patient
 - Justify the questions, managements based on your expected results
 - Explain the biomedical mechanism of the patient’s problem

If you cannot remember the detail of what happened in the video, you can either go back to watch it again or refer to the written transcripts to get the information.

Appendix 3: Transcripts of the clinical case of the Interview

Jeff (later on as T): Mr. Smith, 80 year old man, admitted to hospital because of melena, which was found to be secondary to peptic ulcer disease. Proved by gasdography(PUD), that's why he was admitted to hospital. O.K. his past medical history (PMHx) includes hyper tension, diabetes type II coronary heart disease, he had myocardial infar(ction) in 1999. hypertension, diabetes, coronary artery disease, ah, I think that will be enough. Ok, Let's make it Saturday evening, you are on call, it's 10:00 o'clock in the evening, 10 pm. I am the nurse, o.k. and the nurse calls you because Mr. Smith "doesn't look good". Who wants to try the case?

S1: I'll go.

T: Ok. so, Doctor, um., here is the patient, I am the nurse. I went in to see uh, Mr. Smith at 10 and he doesn't look too good.

S1: what do you mean by that? Was he breathing heavily or having pain?

T: He looks very weak and he seems confused and he is just covered with sweat.

(The teacher add explanation to 'does not look good' as 'confused')

S1: So I can go see him now?

T: you go see the patient.

S1: (I will do) ABCs, so he has narrowing, breathing?

T: ah, ah, ah, when you go to see the patient he is breathing and he isn't making any funny noises

S1: um, can I speak with the patient? Is he cooperating? Is he talking?

T: he is mumbling incoherently. He is mumbling about the war, during world war II. He is going "don't touch me, don't touch me, shoot, shoot"

S1: Alright, so he is mumbling...

T: shoot, shoot,

S1: so ah, I just want to know like previous to what happened, what happen before this, this, situation, I can ask the nurse?

T: well, he is fine, he had his supper as usual, we have been very busy, we don't have as many nurses. A couple of nurses called in sick, so each of us is taking of 8 patients. But nobody had supper, so something looked strange is he usually watched TV, but he did not watch TV this particular time.

S1: So I would give him some oxygen,

T: OK, so you give him some oxygen, right? O.K. (write on the WB), so you give him some oxygen. How much oxygen would you give him, doctor?

S1: 35%

T: 35%, by mask?

S1: Nasal prongs.

T: you want Nasal prongs?

S1: Depending on the patient, since he is creaming about the wars, I do not know if he is going to keep the mask.

T: Shoot, shoot,

S1: So if I try to put on the mask, is he taking off the mask?

T: No, he rips it off.

S1: He rips them off, right? Nasal prongs, he rips them off?

T: No, he keeps the nasal prongs. But When you put the oxygen mask, he will "oh, god,"

S1: Oh, now his vitals.

T: what vitals are you interested in?

S1: I am interested in blood pressure, heart rate, respiratory rate, O2 sat, temperatures.

(T started to write vitas on the WB, after finishing that, he said)

T: Ok, so at this point of time, the BP is 210 over 80, HR is 120 per minute, RR is 30 per minute, O2 SAT before you put on oxygen is 95%, Temperature is 37C.

(After putting on these vitals, there is a silence) the teacher start 'shoot shoot' 6"49'

S1: alright, at this point I am going to exam him. And he let's me he doesn't rip my stethoscope off.

T: Mm.

S1: should I exam him?

T: yes,

S1: O.k. head and neck .

T: what are you going to look for head and neck?

S1: Pupil reaction.

T: the pupil reaction is ok, this is the diagnostic here, (he drew a line the WB to categorize the procedures student took before.

T: so the pupils are equal and reactive.

S1: Is there any signs of, just looking at them, is there any sign of blood, look of bleeding, the sinus, just signs of trauma, facial trauma

T: no signs, no facial trauma.

S1: Ok. what about, is there any bruise... CV and all hospital

T: he does have a bilateral carot bruits.

(Silence)

T: Shoot, shoot,

S1: You want to accelerate my examination?

T: No, I just want to reproduce a little bit ..

S1: Does he have tracheal deviation or anything?

T: The trachea is midline.

S1: Does he seem to be breathing from the accessory muscle?

T: Good question, no use of accessory muscles.

S1: So now on the rest, listen to his lungs, well we can't percuss it

S1: Listen his lungs.

T: No auscultation.

S1: Is he cyanotic

T: He is not cyanotic

S1: So I listen to his heart, because maybe the carotid noise is just I don't know, could be maybe the way it hits him.

T: So there is no heart noises, at this point, the patient BP goes up to 230/80, HR goes up to 140, RR is up to 32, and O2SAT remains at 95%, and T is 37 degrees centigrade, and at this point, the patient is quite somnolent,

S1; Somnolent?

T: Yes, somnolent, he is not going to shoot, anymore, he is just (show the snort), he is covered, just covered with sweat.

S1: So I want to order EKG to see and also what is it before

T: So you want an EKG right away there doctor?

S1: they were probably done before.

T: So EKG, doctor, the EKG is done, and EKG shows sinus tachycardia, and no change from previous, shows some old q waves, and these inferior waves

S1: It's kind of mixed up and probably done... just wondering what the glucose is?

T: so you to do blood glucose, and the blood glucose is low

S1: so he is somnolent now? (repeating and confirming). So I will..

(Long silence)

T: what are you doing if you are on call? You will be on call sometime and you be faced with a case like this, you will have patient dying quickly, you should know shall I be able to manage this case alone? So what will you do?

S1: I will honestly ...

T: What would you honestly do?

S1: I will go for resident.

T: Good, who is going to be the resident? So you are the resident on call.

Appendix 5: Text-based Emergency Algorithm—Prepared by Dr. Jeffrey Wiseman

Task Analysis for Basic Emergencies

The following must be done in order, from A through to E. If, at any time there is a deterioration or new abnormality in a lower letter, one must react by systematically going back up to A and working one's way down again through the task in order from A to E. One cannot go from a higher to a lower letter without first completing all of the tasks under the initial letter.

Airway

1. Check if the patient can **Talk**:
if not, go to the **SECURE AIRWAY** algorithm
2. Check the patient's **Level of Consciousness**:
if deteriorating or if patient somnolent, go to the **SECURE AIRWAY** algorithm
3. Listen for **Stridor**:
if present, check for signs of allergy (urticaria, angioedema)
if present, stop any transfusions or drugs in progress and go to **ANAPHYLAXIS** algorithm
if absent, go to **SECURE AIRWAY** algorithm

Breathing

1. Check **Respiratory Rate, O2 Saturation, Breathing Pattern** (look for paradoxical abdominal wall movement, Kussmaul breathing pattern, or use of accessory muscles):
if normal, go to next step
if abnormal:
 - a. Do an ABG (results available in 10 minutes)
 - b. Rx 100% O2 by mask
 - c. Monitor O2 saturation
 - d. Check level of consciousnessif there is any decrease of O2 saturation or level of consciousness or increase in pCO2 that is unexplained by rapid assessment of the B, C, D, E, or F go to **SECURE AIRWAY** algorithm
2. Check **Tracheal Position and Auscultate Both Lung Fields for Air Entry**: Verify that there are no signs of a tension pneumothorax (verify that trachea is midline, that auscultation of both lung fields reveals no decreased air entry on either side, and that both hemithoraces move symmetrically):
if trachea is shifted AND there is decreased air entry on the side opposite to the side to which the trachea has shifted, think of:
 - a. Tension Pneumothorax on the side opposite to the direction of tracheal shift: Go to **TENSION PNEUMOTHORAX** algorithm
 - b. Tension Hydrothorax on the side opposite to the direction of tracheal

shift (look for central intravenous lines or insertion attempts) or Tension Hemothorax (look for any recent sign or history of trauma or Anticoagulation).

if trachea is shifted AND there is decreased air entry over the same air field side to which the trachea has shifted, think of:

- a. Endotracheal tube is in a mainstem bronchus if patient has been intubated
- b. Mucous plug or foreign body aspiration on the side of tracheal shift: Go to **LARGE AIRWAY OBSTRUCTION** algorithm.

3. Auscultate Both Lung Fields for Breath Sounds:

if diffuse wheezing and prolonged expiratory time, go to **ASTHMA/COPD** algorithm

if diffuse crackles, with or without decreased air entry, go to **PULMONARY EDEMA** algorithm

if diffuse crackles AND wheezing, go to **PULMONARY EDEMA** algorithm

if unilateral crackles, go to **PNEUMONIA** algorithm

Circulation

1. Check Heart Rate and Blood Pressure:

if any of the above abnormal:

- a. Rx 100% O₂ by mask
- b. Get 12-lead ECG
- c. Place on ECG and BP monitor
- d. Start IV D5W TKVO, order/draw cardiac enzymes, electrolytes (Na, K, Cl, Ca, Mg, PO₄, HCO₃) creatinine, glucose, CBC, INR, PTT, Type and cross-Match.

if **Heart Rate** is irregular, >120/min or <60/min: go to **ARRHYTHMIA** algorithm

if **Blood Pressure** is:

> 200 systolic and/or > 120 diastolic, go to **HYPERTENSION** algorithm

<100 systolic or 20 mmHg lower than the patient's usual BP look for vital organ hypoperfusion (decreasing level of consciousness, cold clammy extremities, patient experiencing chest, abdominal or back pain, decreasing urine output):

if no sign of hypoperfusion carefully recheck BP yourself with a mercury sphygmomanometer in both arms:

if repeat BP measurement normal, go to next **C**

if repeat BP measurement still low and/or falling progressively:

check **JVP**:

if **JVP** is flat:

- a. Put patient in trendelenberg
- b. Rx NS Boluses IV as per **INTRAVASCULAR VOLUME CORRECTION** algorithm
- c. Look for obvious hemorrhage:
if present: go to **HEMORRHAGE** algorithm

if absent look for occult hemorrhage:

- i. Rectal exam for blood/melena, aspirate stomach with NG tube for blood or “coffee grounds”.
if signs of bleeding present: go to **HEMORRHAGE** algorithm
- ii. Palpate abdominal aorta for size and tenderness, examine flanks and periumbilical regions for bruising
if present: go to **ABDOMINAL AORTIC ANEURYSM** algorithm
- iii. Palpate all peripheral pulses, check all extremities for gangrene, listen for murmur of aortic insufficiency, look for wide pulse pressure
if present: go to **AORTIC DISSECTION** algorithm
- d. Look for signs of excessive urine, GI, or insensible losses (burns, generalized skin eruptions, fever, “3rd spacing”)
if present: go to **INTRAVASCULAR VOLUME CORRECTION** algorithm
- e. Look for signs of allergy (urticaria, hives, angioedema).
if present: Stop any new drugs or transfusions in progress, go to **ANAPHYLAXIS** algorithm
- f. Look for signs of hypoadrenalism (hyperpigmentation, recent or current use of corticosteroids, unexplained low Na and high K, reasons for or signs of pituitary apoplexy).
if present, go to **ADRENAL INSUFFICIENCY** algorithm
- g. Check the patient’s medication list and stop hypotensive agents

if **JVP is elevated**, order an echocardiogram and:

- a. Look for pericardial tamponade (**Pulsus Paradoxus**, ECG findings of pericarditis or tamponade).
if pulsus paradoxus > 15 and patient not in immediate life-threatening shock (BP < 90 systolic, ↓ level of consciousness), order a STAT echocardiogram
if pulsus paradoxus > 15 and patient is in immediately life-threatening shock, go to the **PERICARDIAL TAMPONADE** algorithm
- b. Look for RV infarction (examine ECG for sign of recent inferior MI, re-do ECG using right V4 lead, get echocardiogram)
if RV infarction, go to **RIGHT VENTRICULAR INFARCTION** algorithm
- c. Look for severe LV failure (risk factors, known low EF, DM, presence of S3, presence of severe sepsis)
If severe LV failure go to **ACUTE LV FAILURE** algorithm
- d. Look for pulmonary embolism (risk factors, signs of cor pulmonale on exam, signs of DVT on exam)
if echocardiogram confirms pulmonary embolism, go to **PULMONARY EMBOLISM** algorithm
If echocardiogram negative or unavailable, order spiral chest CT

Central nervous system

1. Check **Level of Consciousness, Pupils, Best Motor Response to voice or pain**
if ↓ level of consciousness:
 - a. Re-check **A, B, and C** : if these do not explain this picture:
 - b. Check **Capillary Glucose**:
if high: go to **HYPERGLYCEMIA** algorithm
if low: Rx 100 mg Thiamine and 50 cc of D50W IV:
if patient responds, go to **HYPOGLYCEMIA** algorithm
if no response:
 - c. Rx 1 amp of naloxone IVif ↓ level of consciousness PLUS pupillary or motor asymmetry or abnormality, go to **INTRACRANIAL LESION** algorithm
2. Check **Seizure History**:
if history suggests acute seizure or prior seizure disorder, go to **STATUS EPILEPTICUS** algorithm

Cervical spine

1. If setting suggests possible cervical spine injury (MVA, obvious face or head trauma, rheumatoid hand deformities):
 - a. Immobilize cervical spine
 - b. Check **Best Motor Responses, Light Touch and Pinprick, Reflexes** and get **AP and lateral x-rays of all 7 cervical vertebrae**
if any sign of fracture on exam or x-ray, go to **CERVICAL SPINE INJURY PROTOCOL**
if no sign of fracture on exam or x-ray, remove cervical spine immobilization
2. If patient has ↓ level of consciousness without a clear explanation, check for **Neck Stiffness**:
If present, go to **MENINGISMUS** algorithm
If absent, go to **D**

Drugs and toxins

1. Check full **Drug History** (old chart, call pharmacy, call friends or family, check medic-alert bracelet, search patient's personal belongings with witness)
2. Order **Toxin Screen** (ABG, ASA level, Tylenol level, TCA level, AG, osmolar gap, ethanol, barbiturates)
3. Order **Drug Levels** of any of drugs that patient is known to be taking (or might NOT be taking and should)
4. If any of 1, 2, or 3 suggestive of a drug overdose, go to **OVERDOSE** algorithm

Endocrine/metabolic

1. If not yet done, order **Na, K, Cl, Creatinine, HCO₃, Ca, PO₄, Mg, Glucose, ABG**
2. Consider ordering TSH, blood ammonia level, serum cortisol and ACTH, and blood porphobilinogen if the clinical setting is suggestive

Fever

1. If the patient is febrile with no abnormalities in A to E go to **HYPERTHERMIA** algorithm
2. If the patient is hypothermic, go to **HYPOTHERMIA** algorithm

Appendix 7: Complete output of Saturated model

The CATMOD Procedure

Maximum Likelihood Analysis of Variance

Source	DF	Chi-Square	Pr > ChiSq
group	1	4.24	0.0396
session	1	1.87	0.1715
stage	1	4.65	0.0311
DMA	3	71.52	<.0001
group*session	1	0.08	0.7841
session*stage	1	19.89	<.0001
stage*DMA	3	2.95	0.3997
group*stage	1	0.38	0.5372
group*DMA	3	8.65	0.0343
session*stage	3	25.91	<.0001
group*session*stage	1	12.35	0.0004
group*session*DMA	3	7.32	0.0624
group*stage*DMA	3	15.95	0.0012
session*stage*DMA	3	10.14	0.0174
group*session*stage*DMA	3	8.79	0.0322
Likelihood Ratio	0	.	