MECHANISMS UNDERLYING PERCEPTUAL-COGNITIVE EXPERTISE IN ICE HOCKEY: IMPLICATIONS FOR THE DESIGN OF TRAINING SIMULATIONS

by

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ABSTRACT

In this thesis a novel use of the *Recognition-Primed Decision Model* (RPD), and its cognitive task analysis construct, the *Critical Decision Method* (CDM), is described, as a framework for investigating the underpinnings of expert decision-making in ice hockey. The CDM was employed to examine, in situ, the perceptual-cognitive factors used by elite and intermediate-level ice hockey players in the decision-making process. Data was coded and analyzed using a modified grounded theory approach.

The results of study 1 showed that expert hockey players utilize a *recognition-centric* method of decision-making consistent with the RPD model of expertise. Elements from study 1 shown to be most salient to expert decision-making were used in the design of a training tool that targets the *recognition* phase of the decision-making process. Finally, a second study was conducted on a major component of the system to measure its effectiveness for transferring perceptual-cognitive learning to the field.

Keywords: Perceptual-cognitive expertise; Decision-making models; pattern recognition; cue recognition; visual perception; occlusion; ice hockey; cognitive task analysis; grounded theory

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First I would like to thank my co-supervisor Dr. Mike Dobson for his guidance in helping me map out my area of research and zero in on the questions I wanted to explore. His support and direction in the early days allowed me to gain the confidence I needed to pursue my research goals. I would also like to thank my co-supervisor Dr. Robert Woodbury for his very generous support and guidance throughout my entire time in the School of Interactive Arts and Technology. He was always able to help me through any issues that arose, and keep me in sight of the bigger picture. He played a fundamental role in helping me complete this work. A special thank you goes to my supervisor, Dr. Janet McCracken. Janet not only provided me with the theoretical and methodological foundations from which to examine my areas of interest, but, more importantly, convinced me to follow my research dreams, and to focus on the area that I know and love. In the thesis phase of my work she played a very big role, and I could not have completed my work without her generous feedback and direction. I would also like to thank Dr. Brian Fisher for the engaging and enlightening conversations we had with respect to my work, and for helping me to broaden my understanding in the area of perception and cognition. Finally, I would like to thank my family and friends. Their unwavering support is the biggest reason why I was able to complete this work.

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1 INTRODUCTION

1.1 Background

Ice hockey is woven into the very fabric of Canadian life, where the sport takes on a cultural significance far beyond the game itself. Canada's position, as arguably the best skilled nation within the sport, is constantly under examination, from both inside and outside the country. In order for Canada to remain 'at the top of its game' a well structured system, aimed at the development of players and coaches, is in place, and is constantly monitored for areas of improvement. This skill development framework covers areas of psychology, motor skill, team strategy, and perceptual-cognitive skill.

Previous studies indicate that perception and decision-making are more likely to act as limiting factors to performance than the technical and mechanical aspects of movement execution (Abernethy, 1987; Abernethy, 1996; Hyllegard, 1991). These findings highlight the important role that perceptual-cognitive decision-making skills play in producing high performance, and the need for empirically grounded methods that can help coaches and athletes to better understand and develop these types of skills.

The work described in this thesis was driven by the question: *How can technology-based training solutions be designed to effectively enhance perceptual-cognitive decision-making skill in ice hockey?* Several issues immediately arise from this primary question. First, *what are the underlying factors that influence the development of perceptual-cognitive decision-making skill in ice hockey?* While Canadian hockey success has shown that the system, on aggregate, has obviously produced excellent talent assessment and development programs, there is still very little known about the specific perceptual and cognitive underpinnings that influence the development of expertise in this realm. In designing training solutions that target perceptual-cognitive decision-making skill it would seem prudent, therefore, to investigate the precursors that influence the development of this type of expertise. Thus, the next question that logically follows is: *Is there a theoretical framework that can effectively model perceptual-cognitive expertise in the hockey domain, and provide appropriate methodological tools for eliciting the elements of decision-making in a way that informs the instructional design process?*

This thesis first describes a study that was undertaken to characterize the nature of decision-making in ice hockey. As a theoretical framework for this investigation a model of expert decision-making called *The Recognition-Primed Decision Model* (Klein, 1989) was utilized. The RPD was developed to describe the characteristics of expert decision-making in naturalistic environments that impose heavy temporal constraints on decision response. The model stresses the importance of the early *recognition* of familiarity in the decision-making process. More-traditional models of expert decision-making characterize the decision-making process as a rational choice between several alternatives (Janis & Mann, 1977). Further, the RPD framework includes a technique for conducting cognitive task analysis, called the *Critical Decision Method (CDM)* (Klein et al, 1989), which provides cognitive probes, specifically designed to elicit the underpinnings of expert decision-making in the field. The CDM is also said to ‘have applied value in terms of training, system design, or development' (Klein et al., 1989: 464). The findings of this study were incorporated into the development of a learning prototype, designed to enhance a player's ability to recognize and utilize the types of cues and patterns that were found to be most important to decision-making in ice hockey. Results are presented from a second, post-design study that was conducted to analyse the effectiveness of the learning system for transferring learning to the field.

Accordingly, the goals of this research were as follows:

- To uncover the decision-making strategies employed by intermediate and elite hockey players during competition, as well as the salient visual cues and patterns they rely on for decision-making.

- To use these elements in the design of a multi-media simulation to enhance decision-making skill and expertise in ice hockey.

- To examine the effectiveness of such a tool to transfer learning to the field.

- To examine the utility of the *Recognition-Primed Decision Model,* along with the *Critical Decision Method,* as a theoretical framework for describing the underpinnings of decision-making in ice hockey, and as part of a design process for developing technologies to train these invariants.

1.2 Chapter outline

Chapter 2 contains the literature review. First, the general characteristics of perceptual-cognitive expertise in the hockey domain are described, along with an outline of some current learning challenges. Next, some background is presented on the nature of expertise, in general, and sports expertise, in particular. A review is provided of the most common techniques used for training decision-making skill in sport, as well as the ways in which multi-media technology and video are used effectively. Next, a description is offered of the *Recognition-Primed* theory of decision-making, and the potential of the RPD as a model for characterizing decision-making in the sports domain. An explanation is then presented, outlining the methods, including the CDM, that were employed in a study to uncover the perceptual and cognitive elements important to decision-making in hockey. These elements represent the *recognition* phase of decision-making, as described by the RPD, and provide the key areas of content targeted by the learning tool.

Chapter 3 describes the study that was undertaken to investigate the underlying factors that inform decision-making in ice hockey. Players were video taped under game conditions, and were later interviewed on the strategies and cues that they employed in their decision-making process. The CDM was used in the data collection phase, and grounded theory was used to analyse and code the data. The decision-making patterns of expert and non-expert players were characterized within the framework of the RPD, and an inventory was produced of the specific decision-making strategies and cues employed by hockey players during competition.

Chapter 4 presents a prototype that was developed using the decision-making elements uncovered in study 1. The training techniques used by the system are described, and the various system modules are introduced. Chapter 5 outlines a second study that was conducted to evaluate the effectiveness of a major element of the prototype, a computer-animated coach’s chalk-board. The field transfer results are presented, along with a discussion of the possible cognitive advantages that the tool may convey. Finally, chapter 6 reviews the questions that generated this research. Limitations of the work are discussed, along with possible future directions. The contributions of the work are then summarised.

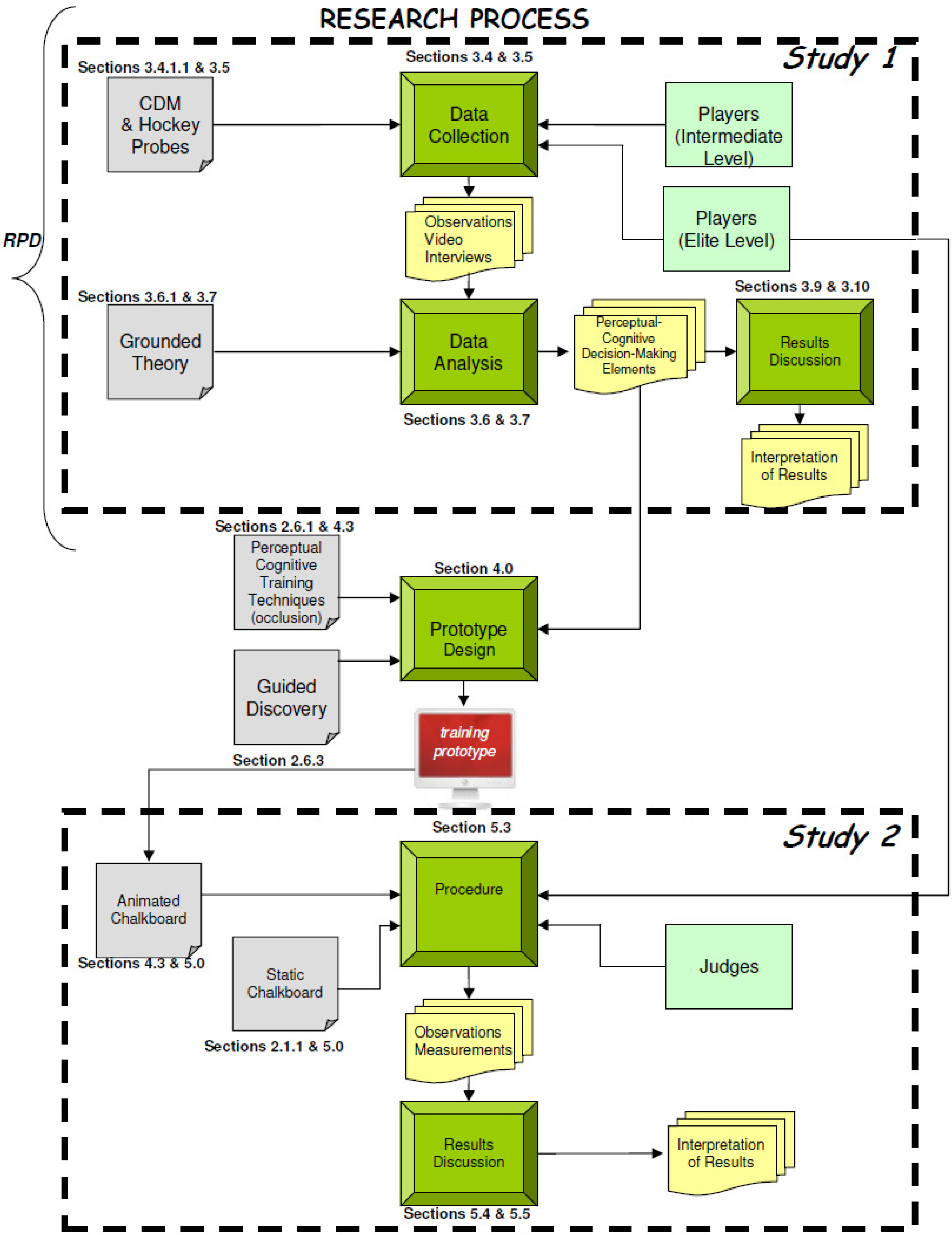


Figure 1.1 Research process

2 LITERATURE REVIEW

2.1 Characterizing perceptual-cognitive expertise and decision-making skill in ice hockey

A team is made up of individuals. These individuals bring a host of different, unique, physical and cognitive talents to the teams they are part of, and these talents need to be nurtured and developed as assets to be used against the opposition. If a team is to be successful however, it cannot simply play as a group of separate individuals, but must also have systems in place that harness the power of cooperation. Thus, the challenge within hockey is to develop a cohesive, cooperative team system, while at the same time promoting individualism. Therefore, along with the development of the physical and motor skills required to play the game, there are two important goals in hockey instruction. The first goal is to teach the strategic and tactical team aspects of the game, while the second goal is to advance the development of the perceptual skills that allow players to make appropriate motor decisions, based on strategic or tactical objectives.

An example of a common team strategy is the ‘breakout’ drill. This play is designed to help a team move out of its own defensive zone and into the offensive zone of its opponent. All players are required to learn the entire sequence of events involved in the drill, as well as each of their team mates’ roles within the overall pattern.

Influenced by strategic and tactical goals, and by the actions of their adversaries, players must also constantly make decisions on whether to pass, shoot, turn, stop, check, etc. From these decisions stem other related decisions involving the application of direction, speed, force, etc., as well as decisions about when to use the above components, and in what combinations. In order to be able to choose the best response, players use their perceptual abilities to pick up postural cues, analyze patterns of play, and assign situational probabilities in an attempt to anticipate future events (Alain and Sarrazin, 1990; Ericsson and Kintsch, 1995; Williams and Davids, 1998). Players with advanced perceptual skills can 'read the play' better, and thus afford themselves more time and space to make correct decisions on how to respond (Williams and Grant, 1999).

Currently, both perceptual and strategic learning occurs simultaneously during practices. The players are introduced to team 'play sequences' or drills (system-based) and are encouraged to showcase and practice their perceptual skills and individual talents while executing these team strategies. In short, both perceptual and tactical/strategic learning are highly intertwined and not easily separated. On the ice these two aspects are taught and practiced together.

Although it is clear that these perceptual-cognitive skills are of critical importance to any player aspiring to the upper echelons of the sport, they are inherently difficult to teach, both because of their subjective properties, and because of the conditions under which they are executed. That is, they are skills that have a unique interpretation for each player, yet are performed within a team setting that requires the cooperation of others for successful execution. Players with adequate physical skills, who learn these cognitive aspects well, tend to advance further, and are more sought after, than players possessing the reverse credentials. Dave King, former Canadian national team coach remarked “give me a player with marginal physical skills, who has learned the thinking parts of the game, and I’ll easily teach him any missing physical parts”. This indicates that players who have developed their perceptual-cognitive skills and have learned team strategy are good candidates for more advanced learning, and thus are more valuable to a team. These players are usually referred to as ‘thinking’ players.

2.1.1 Current learning challenges and rationale

Several learning challenges are evident in the current environment. First, the concepts of strategy and perception are difficult to annunciate and teach. These concepts can mean vastly different things to different players and require much individual attention from coaches. Any instrument that can aid in the learning of these skills would be of great value to coaches and teams in the area of player preparation.

Secondly, X and O diagrams have always been considered difficult for players to comprehend and transfer onto the ice. To examine this statement, and as part of this research, players were asked their impressions of the static chalk-board method of teaching. Anecdotal evidence showed that players have difficulty understanding, through a static chalk-board, the sequence of events that happen over time, especially at interim points within the drill. Ideally, they want information that shows them where one player is in relation to another, at any given point in time. A static chalk-board cannot provide this temporal information. It simply shows the starting points, the path travelled, and the end points. The relational aspects of what happens in between are not evident.

Consequently, this type of relational information is not fully available to a player until the team actually performs the drill on the ice, when players receive direct feedback as to where their team mates are located in relation to themselves. Thus, the transferability from a static drawing, covered with lines and "squiggles", to a real-world system of coordinated group motion is currently a slow, and multi-staged, learning process (see figure 2.1).

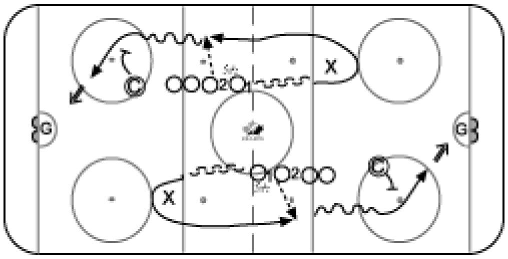


Figure 2.1 Traditional static coaching tool

As a result of these challenges, players come to the rink unprepared. That is, they are told about the learning demands only when they arrive at the rink. They are then shown these concepts through a chalk-board medium that can convey only part of the message, and must take additional time to 'walk through' the process in order to receive a visualisation of the drill that they can emulate. As a result, players are required to process these concepts and execute them, with little time for cognitive reflection.

Furthermore, in terms of simple logistics, ice rental is very expensive, and instead of being able to use the time to immediately practice the concepts learned, players spend inordinate amounts of time in preparatory learning, which should happen away from the rink. Learning tools that can provide players with a more relevant preview of team strategy will afford them more time to understand, and reflect on, these concepts before they arrive at the rink. This, in turn, should make the physical practice time more focused and productive.

Before describing the methods that were used to identify, and design a training prototype to target, these decision-making traits, a review of the field of expertise and decision-making is first provided.

2.2 Expertise

While academics have long been interested in the study of expertise, theories based on cognitive architecture have come to light through research into expertise in chess (de Groot, 1978; Simon & Chase, 1973). These studies heralded the introduction of the expertise/novice paradigm, which compared task performance differences of novices and experts. A seminal experiment comparing novice to expert chess players asked players to replicate the layout of chess pieces that they had just previously viewed. When the arrangement they viewed was random in nature both experts and novices performed similarly well on the replication task. However, when pieces were arranged based on actual chess match patterns, experts were much superior at reproducing the positions of the pieces. The conclusions drawn from this experiment indicated that experts “chunk” pieces into meaningful groups, thus bypassing the conventional working memory limitations of “seven, plus or minus two” described earlier by Miller (Miller, 1956). Put in terms of the emerging cognitive information-processing models, chess experts were said to possess an advantage based on much larger domain-specific LT schema resources, and not on working memory. This ground-breaking discovery laid the foundation for current expertise theories that stress practice and skill development over physical properties or innate talent.

2.3 Expertise and decision-making in sport

In terms of research in the area of decision-making skill in sport, the original literature on perceptual-cognitive skill in sport concentrated on the degree to which expert and novice players could be differentiated on the basis of their visual 'hardware'. Various properties of the visual system were measured, including dynamic visual acuity, depth perception, and peripheral visual range (Hitzeman and Beckerman, 1993; Hazel, 1995; Loran and MacEwen, 1995). The results show that skill-based differences do not emerge on measures of visual function (Hughes et al., 1993; Abernathy et al., 1994) and that perceptual skills, and performance, are not enhanced through visualisation speed training (Helsen and Starkes, 1999; Wood and Abernethy, 1997).

A current review of the literature (Tenenbaum, 1999; Williams et al., 1999) indicates that the key antecedents to perceptual-cognitive skill are;

- the ability to process contextual information using advance postural cue utilization and pattern recognition;
- the ability to use appropriate visual search strategies; and

- the ability to anticipate future events and assign appropriate situational probabilities.

The research also shows that the advanced anticipation and decision-making abilities of expert players are due to enhanced task-specific knowledge bases (schemata), and that performance on recall tests that target this area is the strongest predictor of perceptual-cognitive expertise in team sports (Williams and Davids, 1995). This 'software advantage' (i.e. larger domain specific knowledge base) guides and directs perception, and eliminates the need to assemble production in working-memory, thus allowing the motor response to be available in a minimum of processing time (Paull & Glencross, 1997; Starkes, 1987; Allard, 1980).

In the next section a theoretical construct known as *The Recognition-Primed Decision Model (RPD)* is described. The model characterizes expert decision-making as:

- having the ability to recognize early cues and patterns quickly
- seeing the familiarity of the situation because of a large background of domain-specific knowledge
- not having to use an option-comparing mechanism to arrive at a decision, as non-experts do (Klein, 1998)

This description compares well with the sports expertise and decision-making literature, in describing the mechanics of expert decision-making. The usefulness of the RPD was examined here as a theoretical model for describing and analyzing the underpinnings of decision-making in ice hockey, and as an appropriate framework for developing teaching methods to train the *recognition* characteristics of decision-making.

2.4 A Recognition-primed model of decision-making

Experts in naturalistic decision domains such as air traffic control, search and rescue, fire-fighting and sports constantly make, seemingly spontaneous, decisions based on the instant recognition of vital cues and patterns emerging from the developing state. This ability to make instantaneous decisions is known as naturalistic, or intuitive, decision-making, and is said to be the cornerstone of expertise in environments defined by rapid decision-making (Klein, 1998). This phenomenon has been described by Klein as *Recognition-Primed Decision-Making (RPD).* According to the RPD model, when experts encounter a situation that requires immediate action they rapidly *recognize* relevant cues and patterns, categorize the familiarity and type of situation, observe any inconsistencies, automatically produce a response, cognitively envision and simulate the course of action to ensure its feasibility, and, finally, perform and monitor the selected course of action. This, in turn, initiates a new state which restarts the decision-making sequence (Klein, 1998). *Recognition-primed decision-making* stands apart from conventional models that are based on rational decision-making strategies, because of its speed of execution and its less-deliberate nature. The RPD model was formulated as a construct to describe the rapid, tactical type of decision-making utilized by tank commanders, managers of off-shore drilling rigs, and intensive care medical staff (Ross, Shafer, & Klein, 2006).

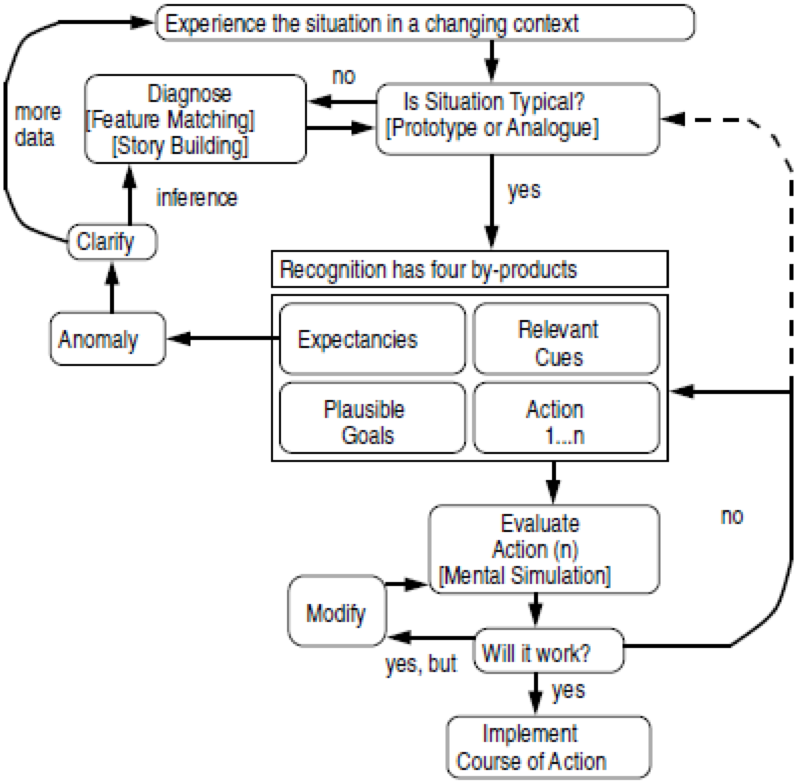


Figure 2.2 Klein's RPD model

In this thesis the approach used for studying and training perceptual-cognitive expertise focuses on the *recognition phase* of the decision-making process, as described by the *Recognition-Primed Decision Model*. Details will be presented on the reasons why recognition skill is an appropriate aspect of the decision process to examine and train. A template will then be provided for using the RPD as a framework for studying and training *recognition* skill.

2.5 Targeting recognition skill to study and enhance expertise

Following on from the research into expertise, showing that experts are defined, at least in part, by their superior recognition skills, it would be reasonable to assume that improving the *recognition* aspect of decision-making might hasten the development of expertise. Accordingly, it would make sense to target this phase of decision-making in order to identify the elements that are crucial to the decision process, and then instantiate these precursors into the instructional design process.

Recognition training is less concerned with decisions made under exceptional circumstances and more with the relatively routine decision situations more-commonly faced by experts. In a study of Firefighters it was discovered that experts were no better than novices at making appropriate decisions under atypical circumstances (Klein, 1998). The same experts performed much superior to novices under routine scenarios. In theory then, it would follow that the low level of cognitive resources expended by experts using the *recognition* technique in routine situations would allow for more resources to be directed to any extraordinary event that might arise.

As described earlier, perceptual-cognitive expertise has been characterized as an ability to use early postural cues and patterns of play to recognize, and encode, advance information for faster decision-making (Abernethy and Russell, 1984; Williams and Burwitz, 1993). This early phase of decision-making is the same phase defined by the RPD as the *recognition phase*, and encompasses the processing of the types of visual cues, patterns, and strategies that are used by hockey players in making decisions.

2.6 How recognition skill is trained

The two most important, and difficult, aspects of designing instruction to train the *recognition phase* of decision-making involve, first, defining the tasks and performance fragments that highlight the salient underlying cues and patterns that experts use in the decision-making process, and then providing appropriate training scenarios that target these tasks, and thus the underlying elements that make them up (Ericsson and Smith, 1991). Thus, the first step in the process is to uncover the specific underlying cue and pattern recognition strategies that are most important to the decision-making process. The next chapter describes the study that was undertaken, as part of this work, to uncover these elements in ice hockey. The test/training tasks that target these elements can take the form of *detection*, *recall*, or *categorization* (Chi, 2006), which all target declarative knowledge, and *prediction* (Endsley, 2006), which targets the more advanced procedural type of knowledge. These methods are incorporated into the design of the learning system described in chapter 4.

2.6.1 The use of occlusion as a technique for training *recognition* skill

Researchers have looked at the question of whether these types of recognition skills can be trained. They have taken techniques that were originally designed for *testing recognition skills* and used them to *train* those same *recognition skills. Occlusion* is used as the primary approach for repurposing testing into training. Occlusion is a method used by researchers to artificially manipulate the flow of visual information available to the subject by masking the display either temporally or spatially. The goal is to constrain the amount of information a subject can access during the lead-up to decision-making, in order to more accurately pinpoint the visual invariants that are most important to their decision-making process. The critical temporal, or spatial, aspect is then targeted for training. In terms of postural cues, for example, Williams and Burwitz (1993) conducted a study of soccer penalty kicks where the subject, acting as the goalie, was required to predict the direction/location of the shot under different limitations of occlusion. The researchers found that there was significant improvement in performance after only 90 minutes of video-based training.

While there has been substantial research into the recognition of postural cues, and the development of training solutions (like the use of occlusion) that target these elements, there has been very little work on helping players to recognize the salient features in patterns of play. (For an exception see Williams, Hodges, North & Barton, 2006.) This is surprising in light of the fact that pattern recognition skill has long been recognized as essential to the development of perceptual-cognitive expertise (Williams and Davids, 1995). There is, however, evidence that pattern recognition skills can be trained through repeated viewing of game-based sequences of play (Wilkinson, 1992), and Williams et al. (2006) further suggest that manipulating temporal aspects of game play patterns, through the re-ordering, or occlusion, of video sequences, may be effective in improving performance.

Based on the above findings, the approach taken in the development of the training prototype was to design multi-media learning tasks that enhance cue and pattern *recognition* skills by utilizing the occlusion paradigm.

2.6.2 The use of multi-media for training *recognition* skill

Multi-media based training approaches that include video have, on the whole, been shown to be very successful for training various aspects of perceptual skill (Abernethy, Wood, & Parks, 1999; Franks & Hanvey, 1997; Scott, Scott & Howe, 1998; Tayler, Burwitz & Davids, 1994; Williams & Burwitz, 1993; Williams, Ward & Chapman, 2003). Williams & Ward (2003) highlight several important reasons why multi-media video approaches are appropriate for training perceptual *recognition* skills in sport. These include:

- The learner can regulate the learning pace
- Training can be provided at any time of year, and is not dependent on external infrastructure
- Injury does not necessarily preclude the learner from training *recognition* skills
- Inexpensive technology
- Information can be conveyed in multiple ways by manipulating video sequences through occlusion and highlighting (Williams & Ward, 2003)

In terms of the level of fidelity that should be incorporated into the design of multimedia simulations for training, researchers in the sports realm have found that when the focus is on training the perceptual-*cognitive* aspects of a skill, the system does not need to also impose, on the learner, the requisite perceptual-*motor* aspects of the skill (Williams, Ward, Allen & Smeeton, 2004). That is, the viewer is not required to physically react to what is happening on the screen in order for learning to occur. Further, for specifically training pattern recognition skills, low-fidelity approaches may be more than adequate, as these skills inherently rely less on perception-action coupling than do postural cue-recognition aspects of decision-making (Williams & Ward, 2003). To this end, Williams et al. (2006) found that information about surface features and postural cues were not necessary for accurate pattern recognition. When temporal sequences of play were shown in point-light form, recognition accuracy was maintained. Subjects primarily used relational information between players (nodes) to recognize the patterns in the play (Williams, Hodges, North & Barton, 2006). These findings are further supported by visual perception research, showing that the human visual system relies almost exclusively on spatiotemporal information to guide object persistence, and that surface features are not useful for tracking objects. (Mitroff & Alvarez, 2007).

Later in this paper, an animated chalk-board tool is described, which was developed as part of a multi-media learning prototype for training pattern recognition skill in ice hockey. The tool utilizes the above findings, including aspects of occlusion, in its design, and presents a visual approach that is similar to Williams and colleagues point-light method shown below.

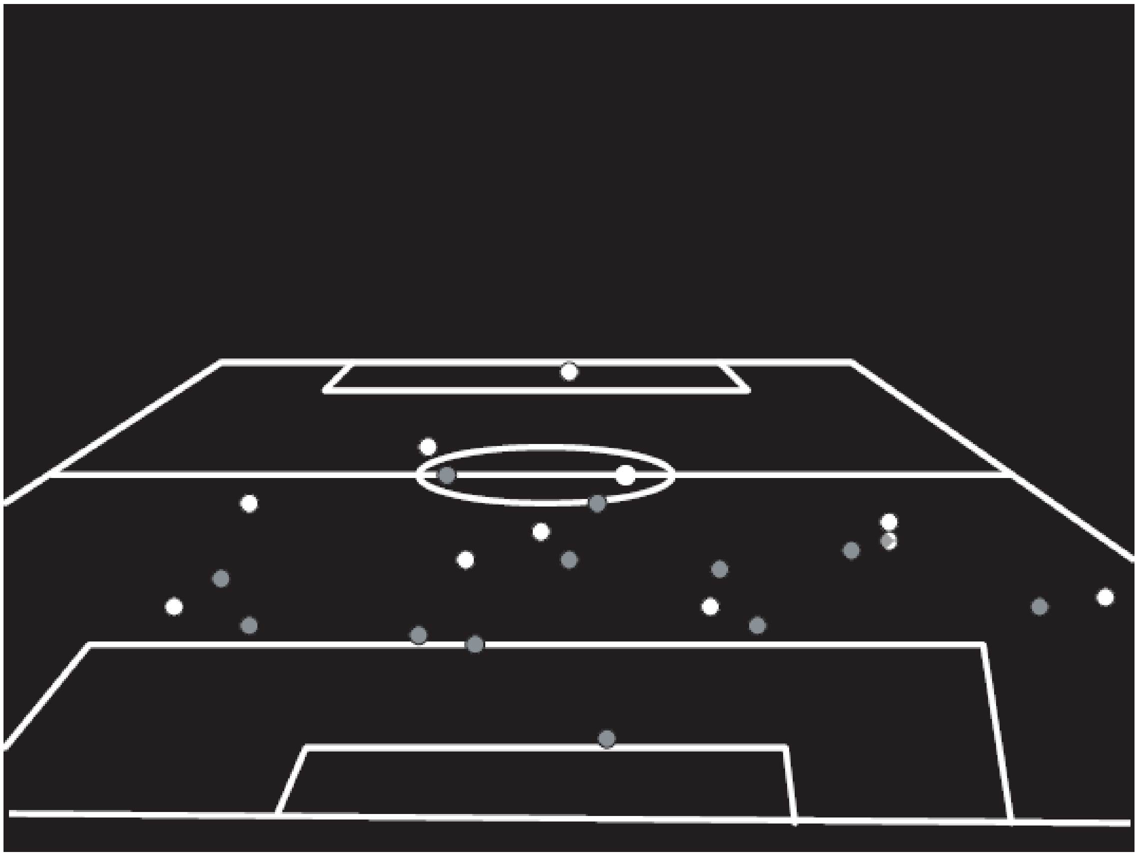


Figure 2.3 Point-light display Williams et al., 2006

2.6.3 Instructional approach for advancing perceptual-cognitive expertise

Finally, we need to look at the way information should be conveyed with respect to training the recognition of postural cues and patterns of play. Traditionally, both perceptual and motor skill instruction was highly prescriptive in nature. Athletes were told, in detailed steps, how to perform a task, and were later assessed for their accuracy in replicating the procedure (Williams & Burwitz, 1993). More recently, researchers began advocating a less prescriptive, more discovery-based approach to instruction (Williams et. al., 1999). It was felt that instruction that was more implicit in nature was cognitively encoded in a way that made it less-impervious to failure under stressful conditions (Liao

& masters, 2001; Maxwell, Masters & Eves, 1999). While these findings arose out of research into *motor* learning, recently, new research on *perceptual-cognitive* skill acquisition has shown for the first time that, under stress-induced conditions, implicit learning, through guided or open discovery, is more resistant to breakdown than explicit learning (Smeeton, Williams, Hodges & Ward, 2005). While it is outside the purview of this thesis to speculate on the cognitive mechanisms underlying this learning effect, these findings are of value to the design of technological training solutions that target perceptual-cognitive learning. Accordingly, the training system (described later) utilizes a guided discovery approach to instructional delivery.

In the next chapter a study is described, which was undertaken to uncover the key cues, patterns, and cognitive mechanisms used by hockey players in the decision-making process.

3 UNCOVERING THE UNDERPINNINGS OF DECISION-MAKING IN ICE HOCKEY: STUDY 1

3.1 Introduction

Current research in the area of sports expertise focuses on examining the precursors to cognitive and perceptual learning in isolation of each other. There have been few studies examining the interplay between these elements in situ. In this study the RPD model (Klein, 1998) of decision-making was used as a framework to examine the spatial and temporal characteristics of the *recognition phase* of decision-making in ice hockey. The goal of the study was to extract the early perceptual cue and pattern recognition strategies utilized by players to inform their decision-making process. By building a better understanding of the antecedents to perceptual and cognitive expertise and decision-making, we can develop more effective and appropriate systems for teaching and training these skills. The results of the study were utilized as content in the design of the learning system described later. The information gathered from this study may also be of benefit to learning situations across other domains, especially those mediated by real-time, visuomotor interaction.

The study was specifically interested in;

(a) Understanding and enumerating the perceptual and cognitive strategies, and any finer-grained precursors, used for decision-making in ice hockey.

(b) The interplay between the different perceptual and cognitive strategies employed for decision-making within a game situation.

(c) The spatiotemporal patterns of their elicitation.

(d) The general patterns of play that precede decision-making.

While it is known that the antecedents to decision-making and expertise in sport are made up of cue utilization, pattern recognition, visual search strategies, and the utilization of situational probabilities (Tenenbaum, 1999; Williams et al., 1999), the goal of this research was to understand what this means specifically for ice hockey. For example, what are the specific cues, patterns, search strategies, and situational probabilities that are utilized in hockey? Are there other categories or attributes that are utilized in the decision process? Can we delve deeper, and find finer-grained elements of the decision-making process? Do these elements interact with each other, or follow any particular kind of temporal pattern? Can a theory emerge that explains the temporal interplay between the antecedents of perceptual and cognitive awareness (and thus decision-making)? Of particular interest were the higher-order cognitive strategies that control the decision-making process. That is, does the overall decision-making process used by experts in ice hockey follow a pattern, as described by the RPD, and how do the decision-making strategies of experts and non-experts compare in this domain? The goal was to use the information from this study to expedite the development of expertise by developing a learning system that helps players recognize these elements of decision-making.

3.2 Participants

The study involved elite (expert) hockey players (n=23) ranging in age from fifteen to seventeen years of age, and intermediate house league (non-expert) players (n=14) of the same age. The elite-level players had played an average of 11.3 years and the intermediate-level players had an average of 6.1 years experience. Participants were informed of the protocol of the study both verbally and in writing, and any under-age participants were required to have parental permission to participate in the study. Parents and coaches were also made fully aware of the procedures involved in the study. Participants were interviewed individually and no information was passed on to other players or coaches. Parents of participant players had the opportunity to request a transcript of the interviews conducted with their children.

3.3 Procedure

The procedure involved;

(a) A preliminary interview of approximately 15 minutes with participants, asking them about their general on-ice decision making processes.

(b) The video taping of participants within a game situation.

(c) A subsequent, post-game interview of approximately thirty minutes utilizing the two videos that had been taken during the game as cognitive prompts to refresh the player's memory. Participants were asked about their decision-making process around plays that were presented from the videos taken of the player in that game.

Individual players were fitted with a small video camera on the front of their helmet that transmitted video back to a laptop computer via a wireless connection. The same player was also video taped from a position near the players' bench. Through these two video-recording techniques the player's view of the game was captured, along with a view of the same player from a distance. Players were video taped one at a time, for approximately fifteen minutes. No more than two participants were monitored per game, due to post-game time constraints.

Figure 3.1 View from helmet cam (right, worn by #10), and same play viewed from the bench (left).

Videotaping and interviewing two participants required approximately 2.5 hours of time (including setup), and two researchers. Coding the data for two participants required approximately 5 hours. Therefore the total time required for each session (game) was approximately 7.5 – 8 hours. For 39 participants the total was approximately 150 hours over 20 games (10 weeks). The schedule for taping/interviews was conducted at a rate of two games (four participants) per week, in order to allow for coding and analysis of the interview data (video data was not coded). Two video cameras were required, one of them portable/wireless, along with two digital audio recorders.

3.4 Data collection methodology

3.4.1 Cognitive task analysis

The goal of cognitive task analysis (CTA) is to elucidate the cognitive underpinnings of decision-making concerning a particular activity, procedure, or event (Hoffmann, Crandall, and Shadbolt, 1998). While CTA usually proceeds with broad-based accounts of a particular procedure, detailed interviews with domain experts make up the majority of the data collection process. The objective of these types of interviews is to gain insight into the cognitive processes employed in performing the task or procedure. Researchers are interested in how experts recognize and interpret vital cues and patterns, how they assess situations, and the meta-cognitive strategies they employ. These task-analyzing methods are particularly productive in helping experts to convey information that is inherently challenging to articulate, in real-time, dynamic environments characterized by uncertainty, complexity, and temporal constraints (Gordon, 1995).

3.4.1.1 The Critical Decision Method of task analysis

As part of the RPD, Klein and colleagues developed a CTA protocol called *The Critical Decision Method (CDM)*, which was specifically designed to analyze decision-making in naturalistic environments that are characterized by perceptually rooted cues. In the CDM, cognitive probes are used to examine expert decision-making (Klein et al., 1989). The tool was developed to a) examine the expert decision-making process, as laid out in the RPD model, b) have utility in the field, and c) provide content appropriate for testing, training, or system design (Klein et al., 1989).

The CDM starts with the selection of a particular incident or decision point. The interviewer then asks for a general overview of the event from the interviewee. Subsequently, the process proceeds in a semi-structured manner, with the interviewer using cognitive probe questions to delve deeper into the underlying aspects of the decision-making process. The result is a transcript that is purposefully rich in descriptions of perceptually-based cues (Klein et al., 1989). Accordingly, this method of information gathering seemed particularly well suited to investigating decision-making in the domain of hockey. The CDM is situated somewhere between a structured approach, like that of an interview, and an unstructured approach, such as a verbal protocol (Ericsson & Simon, 1980). In their purest form, verbal protocol reports can be problematic for eliciting the types of cues that are difficult to verbalize, such as perceptual cues (Klein et al., 1989).

3.5 Data collection process

Klein’s CDM was utilized as the data-gathering framework for this study. A form of focused interviewing was employed, which used cognitive probes, as outlined in the CDM (Klein, 1989). The list of probe questions was modified to include questions more specific to the hockey domain. The process was deductive in nature, in that it was initially populated with several categories. Discussion was provoked around specific decision points that arose from the game play. This is different from the ‘pure’ CDM methodology, where the participant is asked to recall a ‘critical’ incident themselves. Between one and five decision points were reviewed with each player – in total 118 decision points were discussed over the 37 players. This type of interview fit the purpose of this research for several reasons. First, some hypothetically significant elements, patterns, and processes, as well as the overall structure of the situation, was initially analysed by the researcher. Second, pre-determined categories had already been established, which presented the major focus of inquiry and provided a framework of relevance for the data that was obtained in the interview process. Under the aegis of the CDM, the focused interview approach also encouraged the interviewee to continue self-exploration of an experience until some measure of clarity was attained. The findings of Merton, Fiske, and Kendall (1956) lend support to the use of a focused interview approach under these circumstances. Representative probe questions can be found in appendix A.

3.6 Data Analysis methodology

The framework used for analysing the data collected in this study followed a modified grounded theory methodology based on Glasser and Strauss' grounded theory approach (Glasser & Strauss, 1967, Strauss & Corbin, 1990). The approach was modified to allow for a combination of inductive and deductive techniques. Usually grounded theory allows for categories and concepts to emerge through the data collection/coding/analysis process alone.

3.6.1 Grounded theory

Grounded Theory focuses on theory development through the collection and analysis of data. In its traditional form, Grounded Theory structures collection and analysis in a way that allows new theory to emerge. The steps involved in collecting and analyzing data, and theory creation, are all interconnected, and the framework outlines ways in which the researcher moves back and forth between the different steps (Strauss, 1987). Analysis is broken down into three overlapping coding steps. The first is called *open coding*, where data is broken down, examined and categorized. The second step is called *axial coding*, where relationships are made between categories and sub-categories. The final step is called *selective coding*. In this step the primary category is identified, and other categories are refined and linked to this main category. Theoretical sampling (Strauss & Corbin, 1990) is used to guide appropriate data selection so that weak categorical connections can be made stronger, and theoretical sense can be made of the data. To help guide the analysis and promote the building of theory, asking questions and making comparisons are used extensively. Using diagrams and memo-writing are also noted as valuable aids in the data analysis process (Strauss & Corbin, 1990).

According to Glasser and Strauss (1967), grounded theory is well suited to qualitative research because it provides a methodical means of collecting and analysing data. The use of triangulation, using several methods of data gathering (interviews, observation), also contributes to the reliability of the data and enhances confidence in any research findings (Glesne & Peskin, 1992). Lastly, grounded theory is appropriate when the primary purpose of the study is theory development. Through this process, systematic procedures and processes of analysis allow the researcher to develop theory derived from the phenomenon it represents (Strauss & Corbin, 1990).

3.7 Data Analysis process

During the analysis process, a constant comparative method was used to maximise flexibility and support the creation of theory. This was done through systematic data collection, coding and analysis. In the initial process of data coding (*open coding*), as many analytical categories as possible were considered. These included categories defined by the researcher (i.e. cue utilization, pattern recognition, visual search strategies, assessment of situational probabilities etc.) as well as other types of categories which define events during play (i.e. shoot, pass, turn, check, avoid check, receive pass). Categories were primarily coded, however, from the participants' interviews. Finally, observational notes were taken on the video data in order to help corroborate the temporal sequence of events surrounding specific decision points, and the subject's interpretation thereof.

During the subsequent stages of data collection, coding and analysis, an attempt was made to connect categories in some meaningful way. As common patterns emerged in the data, and further data supported these patterns, the patterns were then identified as potential theoretical constructs. The goal here was to attempt to see patterns and similarities within and across categories in an effort to delimit emerging theory. The viability of existing categories was constantly assessed as new data was analysed. If certain categories seemed sparse in comparison to others they were dropped from consideration. When new categories no longer emerged, and the data had no impact on existing categories, the theory was considered saturated. At this point the final stage of the constant comparative method was initiated, which involved the writing of theory.

3.8 Limitations and challenges

Several challenges emerged. First, because the data was initially populated with several pre-established categories for probing, caution was required in order to not overpower the grounded theory approach by bringing already-formulated theories to the process, but rather allow the categories to emerge from analysis of the data. Also, it was initially difficult to know when categories were fully saturated or when theory was stable. Being a subject matter expert helped in this regard, as I brought the knowledge and experience of many years of playing and coaching to the study.

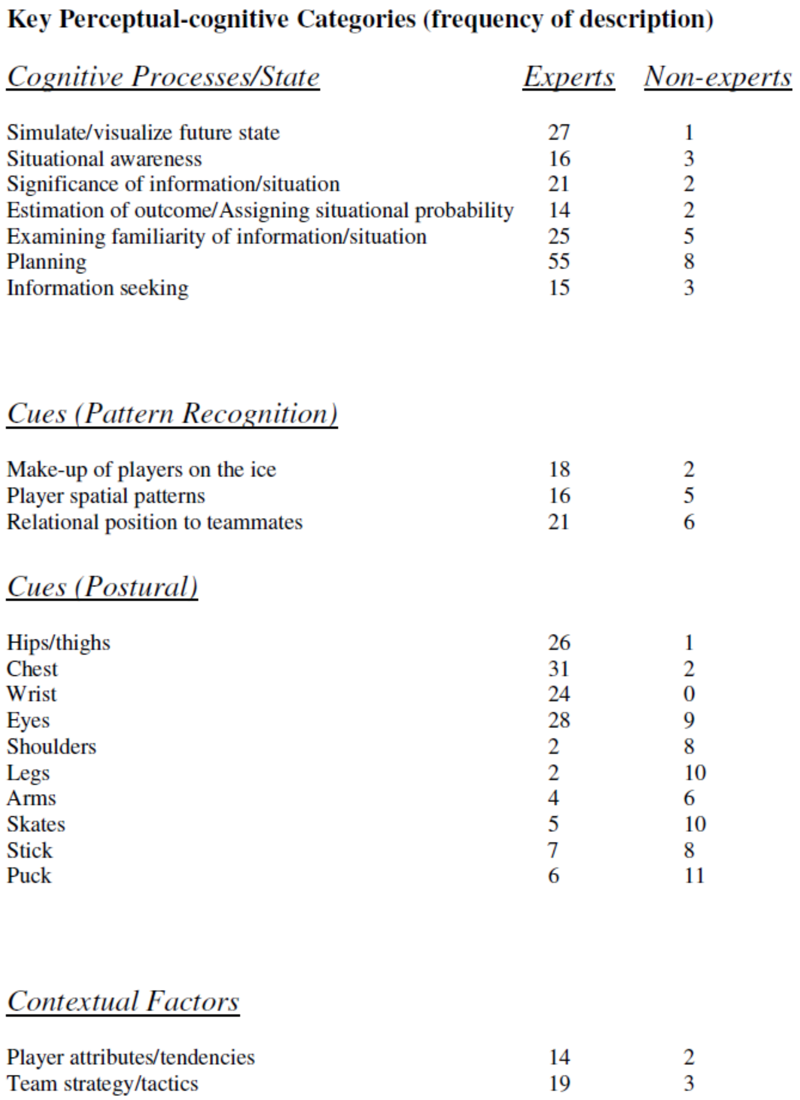
3.9 Results

When players were asked about the information they were using to make decisions on appropriate actions to take, experts and non-experts differed in their descriptions. Experts indicated that visual cues about the relational proximity of themselves to other players (on both teams), the general spatial patterns of players, and specific postural cues exhibited by opposition players, were the features that they most often attended to. Also interesting, were the cognitive processes used by the elite (expert) players to utilize, and make sense of these elements. One of the most common themes described how the elite players used these cues to quickly decide whether they had "*seen this picture before*" or *"been in this situation and how I reacted to it"*. If the player believed they had been in a similar situation in the past they would attempt to execute a manoeuvre (deke, pass, shoot, check, etc.) that they believed had a chance of being successful (because it may have in the past). If the situation seemed more unfamiliar, they would simply "*try something else that seemed closest to the situation*". This process of checking for *familiarity* was one of the most common cognitive themes exhibited by the elite players and was described across all decision time-lines. Two other cognitive strategies that were often employed by the elite players during decision-making involved *simulating or visualizing the future state* and *estimating the outcome* of a decision. These processes seemed to be employed more often when the decision time-lines were in the order of seconds rather than milliseconds. In a very representative decision-point, one elite player described how he *"Noticed how the guy dropped the puck behind his net…I knew he was going to head for the boards and then cut across the middle…they'd been using that breakout all night…I thought, if I fake that I've fallen for it and then cut back* *at the last second I could break up the play…I've used that fake move before and it's worked.* In this decision, the elite player exhibits many of the cognitive processes that set the elite players apart from the non-elite players. This player first attends to *relevant cues* and *assesses* the situation to understand what is unfolding (*situational awareness).* He then uses contextual information about the opposition's *tendencies* and attempts to find *familiarity* in the unfolding situation. When he does, he *simulates, or visualizes* the results of his response and comes up with an *estimate of the outcome.* Finally, he executes his manoeuvre. Decisions like this, involving longer time-lines, seemed to also allow the expert players more time for *planning,* possibly because the decisions, and responses, were less reactive in nature.

In contrast, the intermediate (non-expert) players exhibited a less-refined strategy for arriving at their decisions. These players attended to simpler, less-informative features in the environment, and did not seem to attempt to match features in their visual environment to previous situations. When probed about what they were thinking about during a particular decision, one player stated "*I just wanted to get to the puck first*". When he was asked to elaborate further he was unable to do so, and instead, began talking about the ensuing play. In contrast, comments by some of the elite players faced with similar situations included "*While I was trying to reach the puck, I was looking over my shoulder to see where **** and **** were, because uh, I knew they* (the other team) *had a weak guy on the right side…and I was hoping I could get the puck to **** so we could get in on that side…it worked for us before…"* This clearly shows evidence of *assessment*, *information gathering*, *planning*, and searching for *familiarity*. Intermediate players exhibited virtually none of these cognitive activities. When confronted with a situation, they seemed guided only by the visual information immediately in front of them. In another situation, an intermediate player was asked about a decision he made concerning how he tried to check a player approaching him with the puck. He stated "*he came at me and started to go around me…when I went to knock the puck off his stick he dumped it over to another guy…he* (the player now with the puck) *had got in behind me…I didn't see him…"* When probed about whether there was anything familiar about the situation, or players involved, he said *"I just try to deal with what I see coming…I know how to play a two on one but I didn't know the other guy was there…"* This is a telling statement, which seems to indicate that the player possesses the requisite declarative knowledge about the situation, but has not developed the mechanisms to effectively monitor and use appropriate cues to guide his decision-making. Again, an elite player confronted with a similar situation described it as follows: *"they were coming in and I was the only guy back…I didn't want to commit because he…I…knew he would pass it off…he always passes in that kinda spot…so I tried to stay in the middle and take the pass away* (take away the player's path to make a pass)*…I let* **** (the goalie) *handle the shot…"*. In this exchange, the elite player clearly demonstrates a more refined picture of the situation, which includes an understanding of the *historical* significance of a particular opposition *player's tendencies*, and of the emerging *pattern of players*. This player appeared to be foraging for *familiarity*, as described by the *recognition* phase of the RPD (Klein, 1989).

In terms of the specific visual cues used by expert and non-expert players there were differences here too. The expert players were much more in tune with the spatial and relational patterns of players around them. When questioned on one of his decisions an elite player said *"I knew that they were sending two guys deep so I decided to come back to the half-boards to make a better target for our D (defence)"* This player is showing his awareness of the opposition's tactics by *recognizing* a particular spatiotemporal pattern of players, registering the *familiarity* in the situation, and instituting a specific response. When the player was asked if he had considered any other options he stated "*That was the first one that came to mind that I thought would work…it just seemed like the one that fit the situation."* This is consistent with the RPD, which describes how experts tend to retrieve a response that is 'good enough' or appropriate for the situation, rather than comparing options (Klein, 1998). The expert players typically relied on cues involving eye movement, wrist movement, chest movement, and hip/thigh movement when reacting to one-on-one situations. The non-expert players tended to be mostly oblivious to any purposeful player patterns that emerged around them, and seemed not to assess or process unfolding situations at a deep level. They attended to surface features like the pucks, skates, and sticks and focused on different areas of the body than the experts (shoulders, legs, arms). The key categories that emerged for the expert and no-expert players are shown in Table 3.1 below. A complete list of categories can be found in Appendix B.

Table 3.1 Key Perceptual-Cognitive decision-making elements



Key Perceptual-cognitive Categories (frequency of description)

Cognitive Processes/State	*Experts*	*Non-experts*
Simulate/visualize future state	27	1
Situational awareness	16	3
Significance of information/situation	21	2
Estimation of outcome/Assigning situational probability	14	2
Examining familiarity of information/situation	25	5
Planning	55	8
Information seeking	15	3
Cues (Pattern Recognition)		
Make-up of players on the ice	18	2
Player spatial patterns	16	5
Relational position to teammates	21	6
Cues (Postural)		
Hips/thighs	26	1
Chest	31	2
Wrist	24	0
Eyes	28	9
Shoulders	2	8
Legs	2	10
Arms	4	6
Skates	5	10
Stick	7	8
Puck	6	11
Contextual Factors		
Player attributes/tendencies	14	2
Team strategy/tactics	19	3

It is of interest to note that there were also several socio-cultural themes (categories) that arose from this study. Some players noted that their social relationships with team mates had a bearing on their decision-making process. One player indicated that there were times when he was in a situation in which he would normally have "*made the decision to pass to my right winger but when I looked over and it was ***** then I* *wouldn't pass because we don't get along"*. While these types of interaction clearly have a bearing on the decision-making process, they are outside the purview of this research.

3.10 Discussion

In this section the relevance of the evidence gathered from the study is discussed, within the framework of the *Recognition-Primed Decision Model* (RPD). In the chapters that follow, descriptions are provided on the ways in which the learning system targets the study-derived precursors to decision-making in order to train the *recognition phase* of the decision-making process (Klein, 1998).

In this study expert and non-expert players' thinking patterns were examined during game conditions, to elicit the elements that they point to as important in their decision-making process. Experts indicated that they rely heavily on the familiarity of critical visual cues and patterns that tell them their spatiotemporal position in relation to other players and objects. They use these cues to form a collective 'picture' of the situation, which they in turn try to match with a previously successful response. Accordingly, if players find a prototypical match, they attempt to use a manoeuvre that was successful in the past. If they cannot find a successful situational match they try another manoeuvre, as the next best option. In other words, this study shows that experts seem able to develop a course of action without having to resort to the more cognitively cumbersome comparative analysis technique used by non-experts. As described by Ericsson and Kintsch's (1995) cognitive model of LTWM, experts appear to bypass traditional short-term memory (STM) limitations, by rapidly matching critical cues in the environment directly to schematic structures in LTM in order to determine familiarity. This mechanism is highly consistent with the *recognition* phase of decision-making described in the RPD model (Klein, 1998).

The intermediate level players in the study, on the other hand, seemed to react to situations as they emerged. They showed little evidence of any attempt to ‘read’ the situation, or to look for similarities to past events. They appeared to perform primarily ‘in the moment’, exhibiting little, or no, cognitive filtering of cues in the immediate environment. Rather, they seemed, at times, to attempt to focus on *all* the information in the environment. Randel and colleagues noted that the inability to filter out unnecessary cues can hinder decision-making by creating a state of cognitive overload (Randel et al., 1996). The types of cues that these non-experts did attend to were different from those focused on by the experts, and seemed made up primarily of surface features (stick, skates, puck). These features appeared to be attended to primarily through a bottom-up perceptual mechanism, with very little cognitive interjection In general, the data showed that, from their descriptions, non-experts do not seem to make use of the types of relevant situational events that experts take advantage of, and show little evidence of planning and monitoring. McPherson (1999) found that novice tennis players were not able to monitor, or develop tactical responses to, emergent game situations, and lacked the LTM knowledge structures necessary for efficient encoding and processing of environmental cues.

In summary, the data from this study indicates that the decision-making strategies employed by elite-level (expert) hockey players are different form those of non-experts, and follow a pattern consistent with Klein's *Recognition-Primed Decision Model*. Expert players describe how they utilize a feature-matching approach that uses the familiarity of pertinent cues from the environment to initiate a fast, and appropriate, response. The less-experienced players in the study indicated no such strategy. These results confirm the validity of the RPD model, and the CDM, as a framework for uncovering, and explaining, the decision-making mechanisms, and their underlying elements, utilized by expert ice hockey players. In the next chapter, descriptions are provided on the ways in which the specific cue and pattern-recognition mechanisms used by experts were targeted in the design of a multi-media learning simulation.

4 AN INSTRUCTIONAL SYSTEM FOR DEVELOPING DECISION-MAKING SKILL IN ICE HOCKEY

4.1 Introduction

Video and simulation instruction that teaches the recognition, and efficient use of, postural cues, patterns of play, and visual search strategies, has been shown to be effective in transferring learning to the ‘field’, and yielding improved levels of anticipation and perceptual skill (Adolphe et al., 1997; Franks and Hanvey, 1997; McMorris and Hauxwell, 1997; Murtough and Williams, 1999; Starkes and Lindley, 1994; Starkes et al., 1995; Williams and Grant, 1999). As part of this research agenda, a multimedia learning prototype was designed and built. The system was designed to train the specific precursors of decision-making – those extracted from the previously described study – by targeting the *recognition* phase of the decision process, through both structured and exploratory learning methods. The approaches used will be further explained in the following sections.

4.2 Goals of the learning system

The learning system has two main goals. The first goal is to help teach players the strategic and tactical aspects of the game through the learning of team systems. To help facilitate easier understanding of these types of team drills and play scenarios put forth by the coach, and to aid in the teaching of team systems, the system introduces players to a novel replacement for the traditional static chalk-board used by coaches to diagram plays.

The replacement tool is an animated, executable version of the chalk-board that is more or less self explanatory through its execution. The objective is to better prepare players to practice team drills and concepts as soon as they arrive at the rink. The system facilitates tactical learning by first providing an improved visual representation of the game. In moving away from a static representation of play patterns, and into an animated, time-lapsed view (both flat and 3D), a player can develop a better awareness of the sequence, and timing, of events involved in team drills, and become better able to situate themselves temporally and spatially within those drills. The system also provides instruction on the strategic and tactical aspects of the game through various other multimedia components and activities, using text, video, and audio formats.

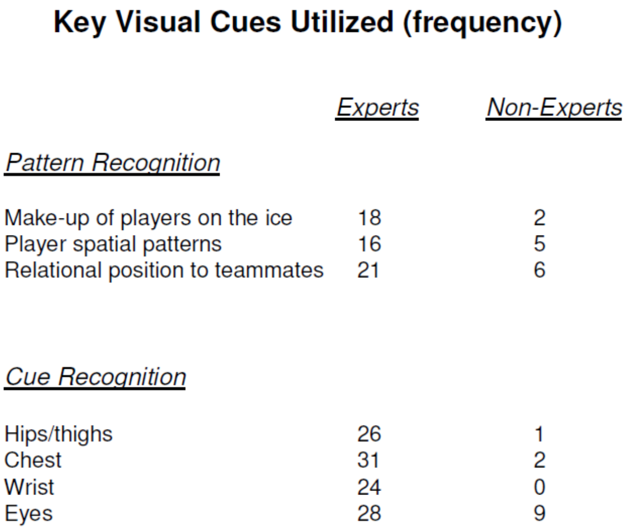
The second goal of the learning system is to enhance players' decision-making ability by further developing their perceptual-cognitive skills - their ability to 'read the play' – by targeting the *recognition phase* of the decision-making process. This enhanced ability to anticipate future events affords players the time and space necessary to make better decisions concerning the application of appropriate motor responses in a given situation (Paull and Glencross, 1997).

4.3 Targeting the *recognition* phase to train decision-making: Mapping the findings from Study 1 to the learning system

The learning system utilizes knowledge about the most salient elements expert hockey players utilize in the early phase of decision-making (obtained from study 1), and targets this *recognition* aspect (Klein, 1998) for learning and transfer. Specifically, the learning system targets the key *visual* cues found to be most important. These cues are a sub-set of the much larger list of categories that emerged from study 1 (Appendix B). The cues fall into two categories – *pattern recognition,* which highlights spatiotemporal relationships among players, and *cue recognition,* which emphasizes the key postural features that guide expert decision-making in hockey. The specific cues that are highlighted for training in the system are shown in table 4.1 below.

The system is designed to improve a player's ability to recognize and utilize these specific advance cues, and patterns of play, in their decision-making process. This is accomplished using occlusion as a major component of the instructional design strategy. For example, to help players learn about postural cues, a single area of the screen (i.e. a player's arm, or wrist area) may be blacked out for the entire play sequence (spatial occlusion). In other situations the entire screen may go black for a brief period of time (temporal occlusion). Spatial occlusion targets the area *where* experts look to gain an edge. Temporal occlusion focuses on the point in time *when* an expert has an advantage. In each of these learning scenarios, the learner is required to either decide how to react, or to predict what will happen next. The system progresses the learner toward the expert level by gradually moving the occlusion points (spatially and temporally) closer to the point where/when an expert would have the optimal advantage. While it is not currently implemented in the prototype, a similar approach could be taken with respect to learning patterns of play. Currently, the animated chalk-board highlights the relational features utilized by players (see Table 4.1) in understanding on-ice patterns of play without the use of occlusion. Williams et al. (2006) suggest that re-ordering temporal sequences of play, or blacking out certain action sequences, has shown promise for training pattern-recognition skill. This technique will be incorporated into future revisions of the animated chalk-board.

Table 4.1 Visual cues targeted by the learning system



Key Visual Cues Utilized (frequency)

	Experts	*Non-Experts*
Pattern Recognition		
Make-up of players on the ice	18	2
Player spatial patterns	16	5
Relational position to teammates	21	6
Cue Recognition		
Hips/thighs	26	1
Chest	31	2
Wrist	24	0
Eyes	28	9

The following sections provide further detail on the components, activities, and instructional strategies that the system utilizes to promote learning.

4.4 Overview of the design components of the learning system

The learning system consists of a multimedia, web-based simulation engine, designed to animate, and put into motion, the sequence of events involved in different game strategies and concepts. Players are able to see a ‘run through’ of the events, rather than simply viewing the process on a static chalk-board. The simulation consists of an animated ‘flat’ chalk-board, as well as a 3D computer-animated game-like display of the same sequence of play. The computer-animated display provides several views of the game from the player’s perspective, including a view from an individual player on the ice (egocentric) and a view from players on the bench (exocentric).

The system follows a blend of tutorial-based learning and exploration, with the *Tutorial* module concentrating more on individual perceptual-cognitive training, while the *Analyst*, *Coaches Plays*, and *Create* modules favour tactical learning. The system has a web-based communication interface, where players can share their experiences through Computer-Mediated Conferencing (*Ask* module) and challenge the effectiveness of each others’ tactical designs. Professional game video clips are used to augment learning and text and audio explanatory methods are employed in all modules.

As described earlier the system employs a guided-discovery approach to learning. Learners are directed to salient areas of the screen and invited to expand on, or further explore, specific cues, patterns, or strategies that might be highlighted.

4.5 Activities designed to enhance decision-making skill

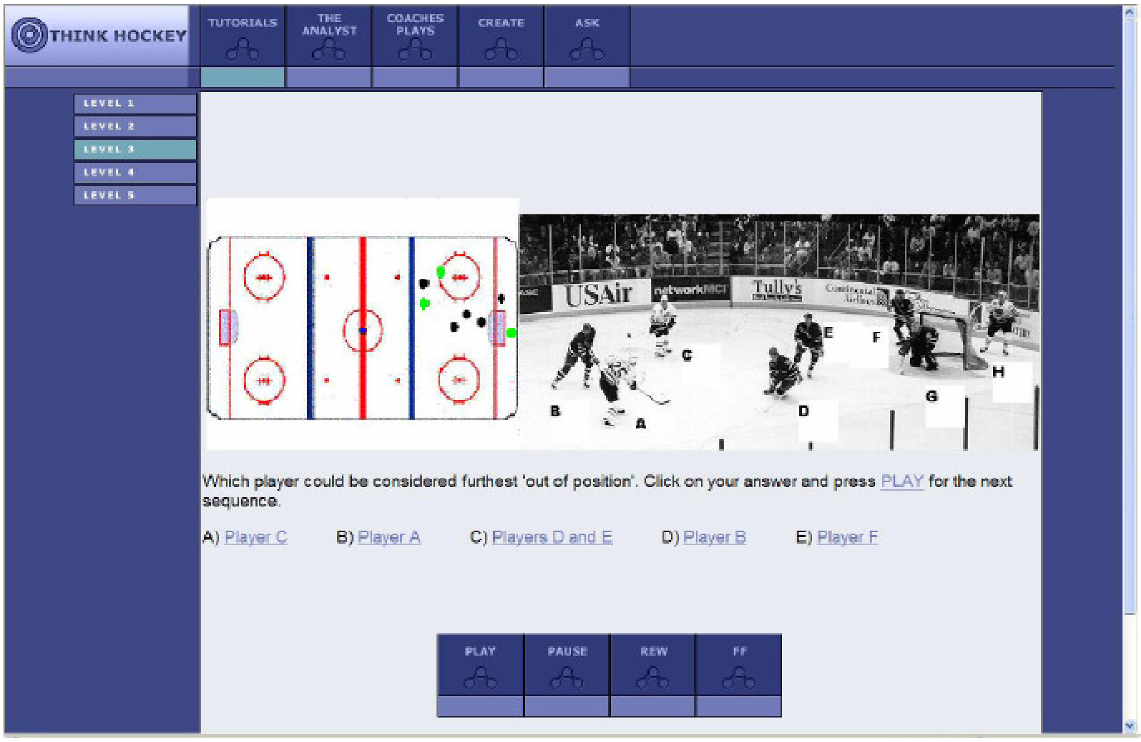
4.5.1 *Tutorial* Module

This part of the system is designed to both familiarize the learner with the animated chalk-board and promote perceptual and tactical learning. This is done by presenting real game situations through video clips, where the animated chalk-board emulates, or follows, the video clip from a ‘birds-eye’ view. The focus of the module is on advancing cue and pattern *recognition* skill. Multiple choice questions are presented, based on what transpires within a video/animation sequence. The player may replay the video/animation any number of times before answering the questions. Players are also presented with clips that stop at a specific point in the action. Learners are then asked questions as to what will happen next, or what a particular player in the video should do. Some of these play fragments include spatial or temporal occlusion, in order to present an impoverished visual landscape to the learner, and thus focus their attention on the most salient cues available within the display kinematics. Williams and Grant (1999) indicate that perceptual abilities can be trained by using simulation, in the form of videos, where a play sequence is presented and stopped at a critical point and the viewer is then asked to elaborate on what is happening, or what is about to happen. The goal is to have learners choose a future response based on the lead-up information presented by the clip. This lead-up information also includes explanations on how to use specific advance recognition cues (body language, patterns of play, etc.) – those taken from study 1 - to help the learner anticipate future events (Franks, 2000).

Consistent with the *Recognition-Primed Decision Model* (Klein, 1998), these exercises enhance a player's ability to recognize the emergent features of a pattern of play early in its initiation (Klein's *recognition* phase), thereby facilitating anticipation and effective decision-making (Williams and Grant, 1999). They also help the learner discover valuable informational cues, uncovered in the earlier study, on the positioning of various players, and how this corresponds to a subsequent action – another important piece of information used in effective decision-making (Williams et al., 1999; Abernethy, 1990). Lastly, the system can help players enhance their decision-making (*recognition)* skills as they learn to assign subjective probabilities to those events likely to occur within a given situation (Alain and Sarrizin, 1990).

The module provides brief audio and text explanations of various game concepts and strategies, along with advice on how to use the hockey-specific, advance cueing techniques (extracted through the study) to anticipate future events. Because of the potential for problems maintaining students' focus with this type of environment, video clips (less than 10 seconds) and text length, are both kept to a minimum. All exercises completed by the learner are saved by the system and are available to the coach for review.

The tool is adaptive to the student's progress in relation to the tutorial-set goals, and advances the student accordingly. That is, extrinsic feedback is provided based on the goals of the lesson. The student is, however, permitted to override the pace at which the tutorial advances. Several of the tutorials are designed to transition players to the animated chalk-board view, by showing some sequences exclusively in the animated view.



Which player could be considered furthest 'out of position'. Click on your answer and press PLAY for the next sequence.

A) Player C B) Player A C) Players D and E D) Player B E) Player F

Figure 4.1 ***Tutorial*** **module**

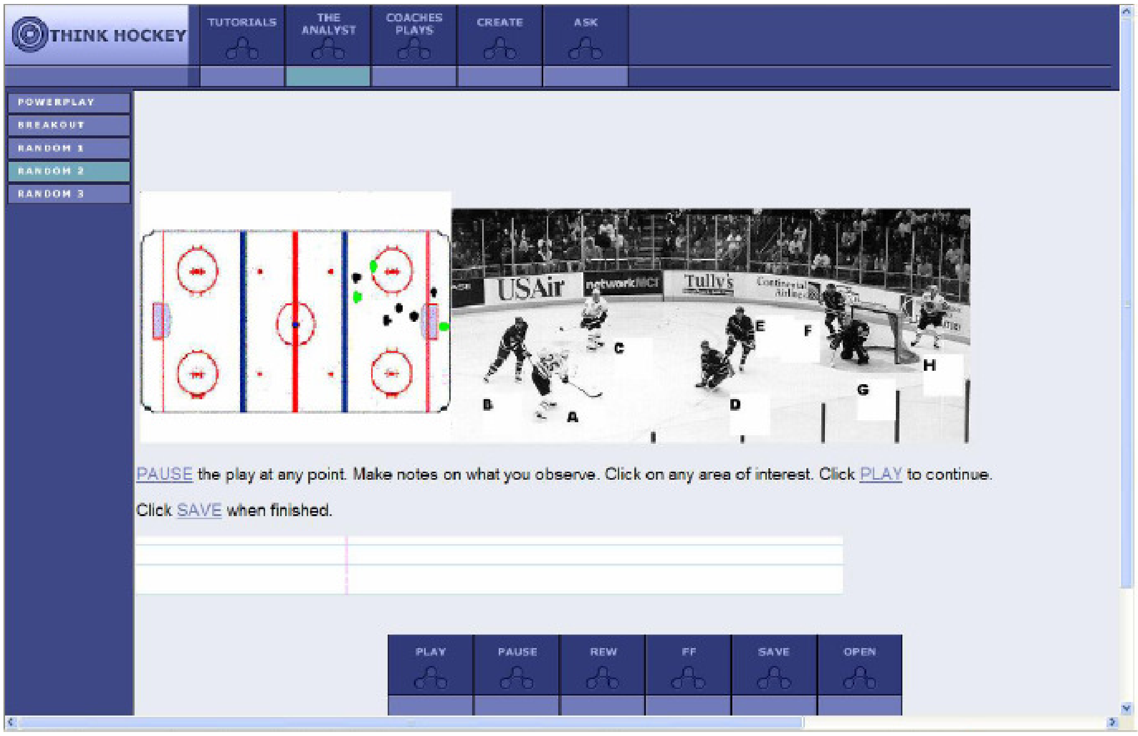
4.5.2 *Analyst* Module

The aim of the analyst module is to allow the player to emulate a ‘TV hockey analyst’. Learning is targeted more towards team-based tactics (pattern recognition) and less toward perceptual enhancement (cue recognition). The player is presented with a video sequence of between 30 and 60 seconds. A corresponding chalk-board animation of the play accompanies the video. Instructions (audio and text) are provided by the coach at the beginning, before the sequence can be started. These instructions include brief explanations of some of the concepts that the sequence may show. General instructions provided to the player explain that they should watch the video and chalk-board and can pause at any point. At this time the player can click on any area of either the video or the chalk-board and annotate what they see happening (either positively or negatively). An example might include a learner pausing the action, clicking the mouse in two spots on the screen, and making a note that the two players indicated are ‘out of position’, compared to where they *should* be. Occlusion is also used in this module in order to highlight the important spatial relationships among players, and to help learners come to understand the minimum essential relational information required to make decisions. The coach can also use this technique to assess how a player’s level of *recognition* skill is progressing. The module is interactive, in that the learner may pause, and annotate, the action as many times as they like, and when finished may save their results to a file. This type of data capture is modeled on the techniques employed in social science research for studying human interaction using video and audio (Muhr, 2000; Patton, 2002). The data is available to the coach for review.

The learner has the opportunity to use the knowledge they have acquired through the tutorial module and apply it in the analyst module. The system directs the learner to the salient cues and patterns derived from the earlier study. They can practice the skills they have acquired using cues, patterns of play, and situational anticipation in an attempt to further their overall decision-making ability by enhancing their *recognition* skill. The learner reinforces their *recognition* skill through their own intrinsic feedback, as they view the clips. That is, they can guess at what might happen next, while they are, at the same time, critiquing the team-based strategies that unfold.

The student is asked to use their existing background knowledge to critique various situations and come up with their own interpretation. The student is encouraged to investigate the information presented and to negotiate their own goal task. Intrinsic feedback is evidenced by the confidence that the learner can gain in commenting on areas that they know to be correct. That is, because the learning goals are set by the learners themselves, intrinsic feedback is primarily a reinforcement of concepts and knowledge already known (Laurillard, 2002).

The learner also receives extrinsic feedback from the coach (acting as a guide), and from other players, on the analysis presented. These discussions can occur through email or the CMC system. Learners can reflect on the feedback they obtain and then return to the module to review, and make new comments on, specific plays. Learning is different for each player and thus the coach must guide individuals to find their own new meaning through their own analysis.



PAUSE the play at any point. Make notes on what you observe. Click on any area of interest. Click PLAY to continue.

Click SAVE when finished.

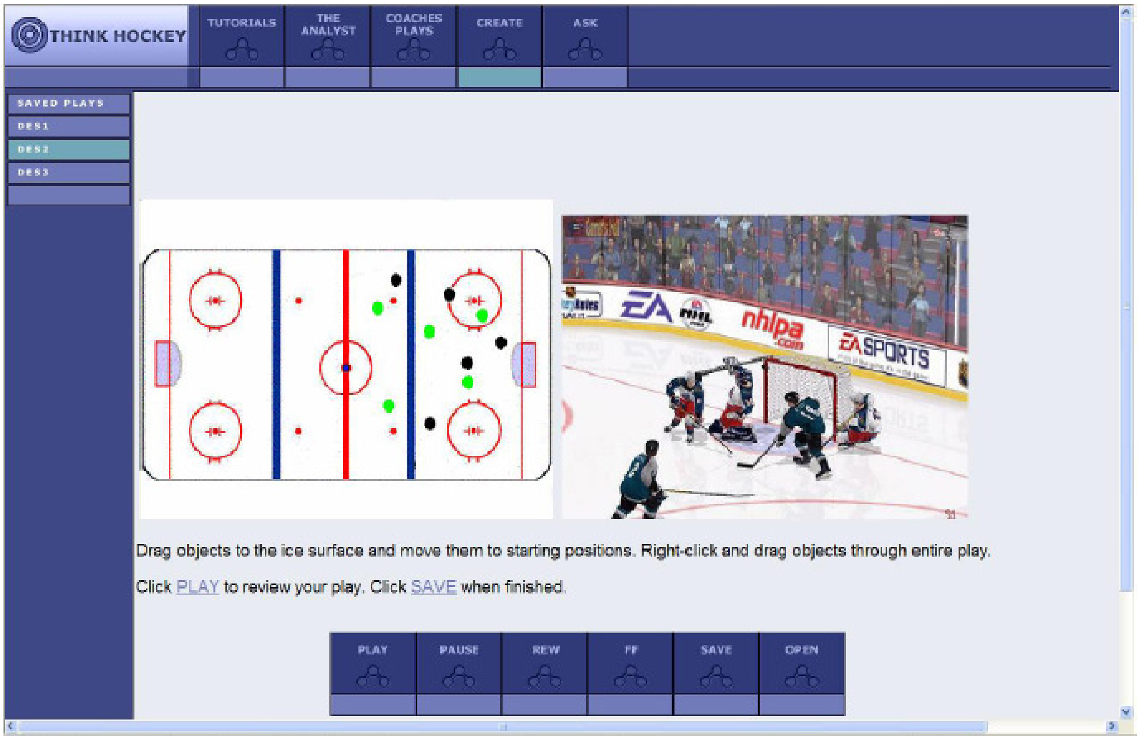
Figure 4.2 ***Analyst*** **module**

4.5.3 *Create* Module

The Create module provides a vehicle for the learner to design their own scenarios through a guided-discovery approach from the coach. This module attempts to blend the learning of team strategy with perceptual learning. The learner builds their play sequence by manipulating players either within the ‘flat’ animated chalk-board view or via the 3D computer-animated view. They can also view their creation from either the chalk-board animation or from multiple perspectives using the 3D computer-animated game-type displays.

As the player ‘runs’ their scenario they receive intrinsic feedback on the relative positioning of players, and can reflect on how likely their scenario is to be successful in the real world. They can then adapt their program, based on this intrinsic feedback. The module is highly interactive and allows the player complete control over goal-setting. The player may save their programs, which then become available for feedback from the coach and other players.

The learner has control over positioning of individual players (of both teams) within the simulation and, by running the simulation, can receive intrinsic feedback as to the likely success of their design (i.e. A goal is scored or not). Learners can challenge each other by setting up strategies to counteract another learner’s existing scenario. In running the resulting response scenario against the original (now two created teams are in action), the original developer receives valuable feedback as to any possible flaws in his or her plan. In building a sequence of events of this kind the learner is able to enhance their *recognition* skill through an understanding of the spatiotemporal interrelationships that occur on the ice, and the effects caused by the timing of decisions.



Drag objects to the ice surface and move them to starting positions. Right-click and drag objects through entire play.

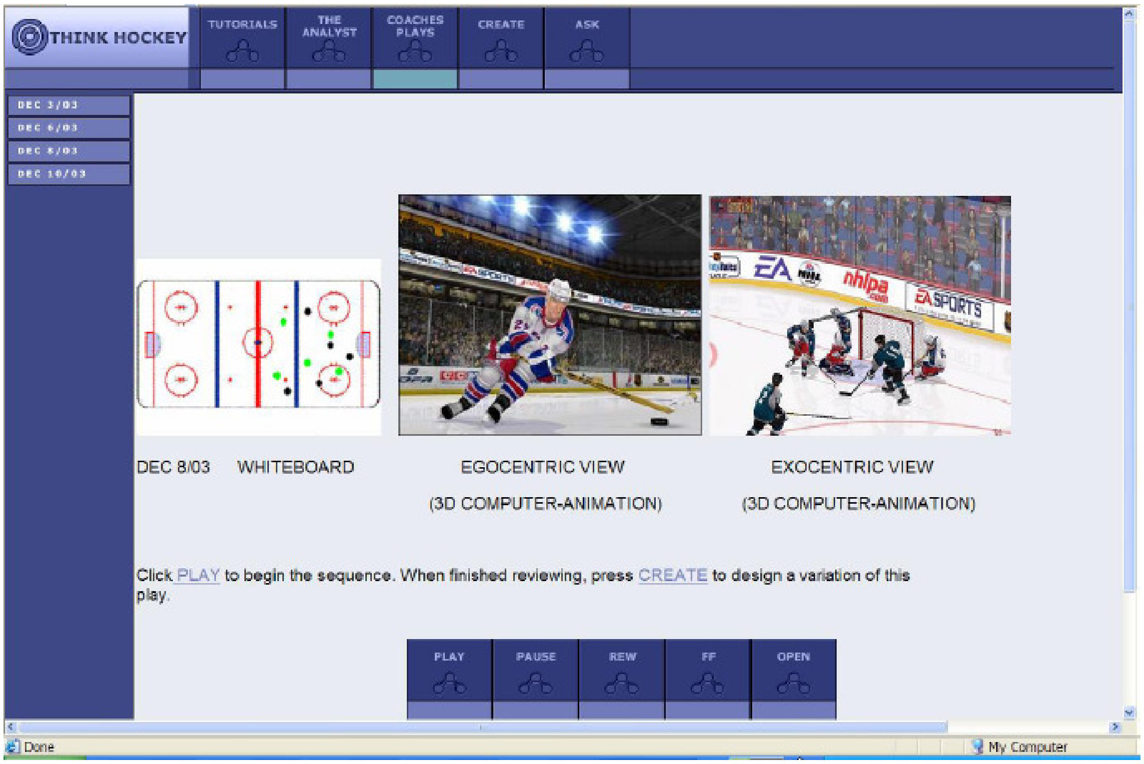
Click PLAY to review your play. Click SAVE when finished.

Figure 4.3 ***Create*** **module**

4.5.4 *Coaches Plays* Module

This module is designed to be read-only. It is used by the coach to upload drills and plays that the players must learn. These are team-based sequences and are displayed both in animated chalk-board format as well as 3D computer-animated player (egocentric and exocentric) views. As in other modules, text and audio explanations accompany the visual representations. The system can provide hints, based on the information derived from the study, on the salient features and strategies that players use in the *recognition phase* of the decision-making process (Klein, 1998). The coach can turn different aspects of occlusion on, in order to highlight (blank out) the trajectory of a certain role (player) in the drill sequence. Players are then encouraged to mentally simulate the missing trajectory and its spatial relationship to the other participants in the drill. Players are able to review and learn these scenarios before on-ice practice, and may be further directed to comment on their understanding through the CMC system (‘Ask’ module), or to provide their own variation on a drill using the ‘Create’ module.

Research shows that computer-animated training (also utilized in the Tutorial, Analyst, and Create modules) can enhance perceptual learning if the viewer’s attention is directed towards important features of the display through video simulation (Christina *et al.*, 1990; Williams and Burwitz, 1993; Singer *et al.*, 1994). The role of the coach is to utilize the important postural cues, and patterns, derived from the earlier study, that might aid perception, and guide the learner to those elements in the display. Magill (1998) also noted that attention should be directed toward ‘information rich’ areas of the display in order to provide the learner with the opportunity to acquire knowledge implicitly. This technique has been shown to transfer well to field situations (Franks and Hanvey, 1997).



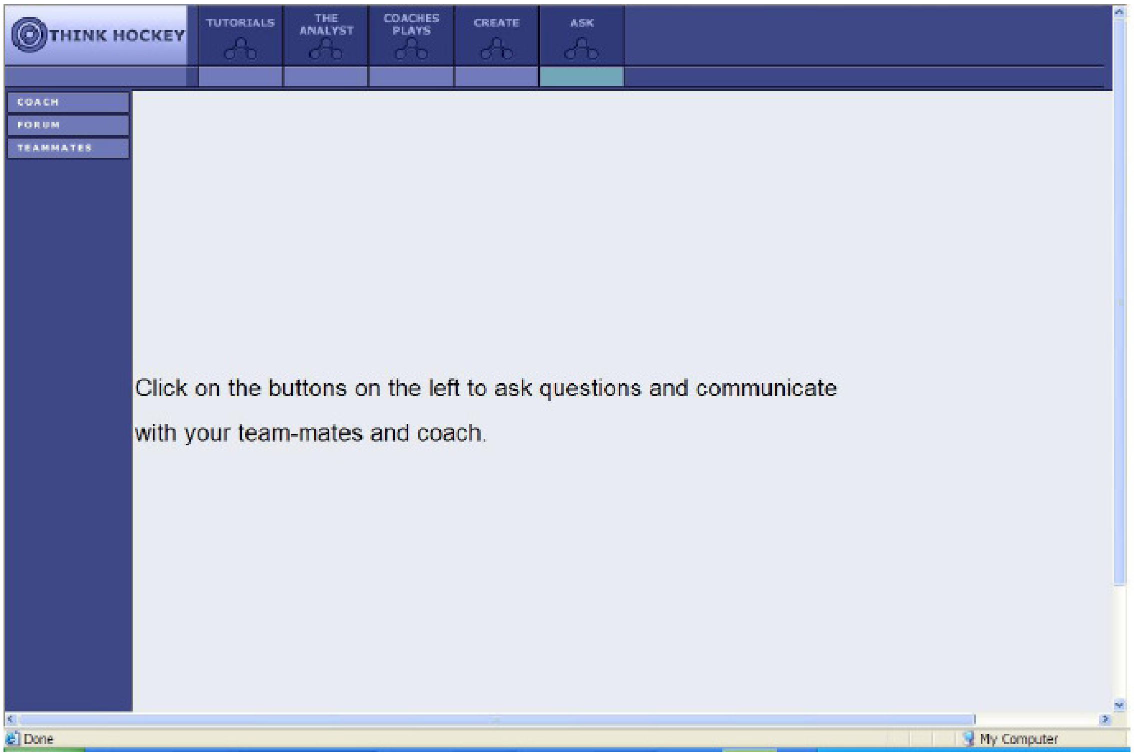
Click PLAY to begin the sequence. When finished reviewing, press CREATE to design a variation of this play.

Figure 4.4 Coach's *Plays* module

4.5.5 *Ask* Module - Computer-Mediated Conferencing

The 'Ask' module is designed to promote articulation and reflection. Learners are encouraged to share their questions and comments with their team mates and coach. A part of the module is accessible only to players, in order to facilitate a frank exchange on issues that may be important among players. The aim of this type of discourse is to promote a sense of team solidarity through open discussion and collaboration.

The coach also plays a significant role in the open forums by promoting discursive and reflective activities. These include answering questions that the players may have about their roles within the team systems, or clarification of concepts that have been presented by the coach. Players can respond to other players' challenges or suggestions by reflecting on, and re-articulating their own understanding of a particular 'play' or strategy. The coach can encourage players to discuss their own variations on team strategy with their line mates (those players that they usually play together with) in an effort to help the players build their own understanding of the drill or concept. The coach can guide or steer conversations into productive areas and encourage players to contribute through timely feedback.



Click on the buttons on the left to ask questions and communicate with your team-mates and coach.

Figure 4.5 Ask module

4.6 Assessment of learning progress within the system

The learning system is not designed to be used within a formal academic environment but, rather, for training the cognitive attributes of ice hockey players. As a result, grades and other objective markers are not employed as an assessment strategy. Rather, this system favours, and is designed around, an ongoing assessment of activities in authentic settings (Shepard, 1991).

Laurillard states that one of the advantages of learning technologies is that, if designed correctly, they can provide for automated data capture that can be used in assessment (Laurillard, 2002). Willis and Wright (2000) advocate the use of projects, portfolios, activity logs, and journals as being effective assessment vehicles within a learning system. All modules of this system utilize versions of the above techniques and are designed to capture various forms of data that can later be used to assess the overall comprehension level of players.

The *Tutorial* module, through its multiple-choice approach, presents the only data within the system that could be considered objectively measurable. In this module, learners receive direct feedback on their accuracy in predicting future events and situations, while the logs of the answers are saved for later review by the coach. The coach, in turn, can review the exercises with the player and provide feedback on new approaches that the player might take to further their understanding and development of perceptual-cognitive awareness.

As was discussed earlier, the *Analyst* module utilizes an approach used by social researchers to capture data by annotating video and chalk-board events. This data gives the coach a perspective on the player's critical thinking skills and reflective capabilities, along with good feedback on the players' grasp of different strategic systems and concepts.

In the *Create* module, the data saved is solely of the player's design. Again, this type of data allows the coach a window into the players understanding of concepts, as well as an assessment of how well a player can 'think outside the box', or be creative through their designs.

The *Ask* module houses the forums and conferencing system used by the players to collaborate and share information, both with each other and the coach. This module promotes the type of social negotiation and collaborative learning that can result in peer-assessment playing a role in the learning process.

4.7 Assessment of learning transfer to the field

It is important to note that the bulk of cognitive skill development and strategic learning that occurs in hockey players takes place on the ice. The playing environment is also the final arbiter of the learning that is facilitated through the multimedia learning environment outlined here. Coaches should be able to determine whether their players are coming to the rink better prepared, and to assess the level of understanding imparted by the learning system.

The formal measurement of *transfer* is one of the most difficult issues facing research into expertise, because of the difficulty in assessing the relative contribution of a particular instructional intervention to increases in field performance. Williams and Ward suggest that the opinion of expert coaches is one valuable method for assessing transfer (Williams & Ward, 2003)**.** To this end, a second study was designed, which utilizes the judging expertise of experienced coaches to measure the learning transfer of one of the key components of the training system. The study is described in detail in the following chapter.

5 MEASURING SKILL TRANSFER OF THE LEARNING SYSTEM: STUDY 2

5.1 Introduction

Having designed and built the system based on the findings from study 1, an evaluation study was undertaken to validate both the design and the learning effectiveness of the training system. In order to assess the effectiveness of the training system in the field, this study was designed to examine one key component of the system, the animated coach's chalk-board. This module was developed to replace the traditional 'x and o' static chalk-board that has been used in the field by coaches for many years. The goal was to compare the teaching effectiveness of the dynamic system to that of the traditional static chalk-board.

The study is a qualitative evaluation, in which the following types of data were collected and codified; expert scores on player performance, observation data of player performance and informal post-trial interview data from both players and the expert judges. Together this data provides a picture of the way in which a dynamic learning tool helps support the task of learning the strategic aspects of hockey play. The study setup is described, along with the data collection and analysis procedures. The results are then discussed in light of the types of cognitive mechanisms that may be at play when using such a tool.

5.2 Participants

The participants were 12 elite male hockey players between the ages of 15 and 17. These players were familiar with the traditional techniques of diagramming tactical plays, and understood the symbolic ‘shorthand’ used by coaches to communicate using this medium.

5.3 Procedure

The study consisted of one session of approximately four hours. Players were randomly divided into two groups (n=6). The two groups received instruction on how to execute a novel tactical drill. One group was given instruction (individually) by a coach using the traditional chalk-board to diagram the drill. The other group was shown the same drill (individually) on the computer-animated chalk-board. The time allocated for the instructional process with the static chalk-board was based on similar training situations in the past (approximately 10 minutes). The same amount of time was allocated to players viewing the animated version of the drill, although no player took longer than 6 minutes to prepare themselves with the animated technique. Instruction was provided one-on-one, just prior to the player performing the drill, with the coach describing how the drill should unfold, while at the same time demonstrating the drill with the assigned tool. Players viewing the animated version were permitted to replay, pause, and ‘slow-mo’ the drill as needed. Players viewing the static chalk-board were encouraged to ask questions if they felt confused as to how the drill should be carried out.

Six additional elite players from another team were recruited to pre-learn the target drill, and act as ‘choreographed’ team mates during the execution of the drill. These players filled the positions of the usual 6 man unit on the ice – a goaltender, two defensemen and three forwards. However, the goalie and two defensemen acted as opposition players for the purpose of the drill. The drill took the form of a three-on-two offensive attack, and was designed as a tactical tool for forwards. Accordingly, the specifics of the drill did not apply to the two defensemen who were directed to simply defend against the forwards. Because of this, all the participants chosen for the study were forwards (four left-wingers, four centres, and four right-wingers). When a participant was required to execute the drill, he simply took the place of his corresponding ‘choreographed’ line-mate on the ice. For example, a right-winger would ‘sub in’ at right-wing; a centre would ‘sub in’ at centre, etc. This was done in order to avoid the confounding factor of a forward having to play out of his normal position, and, thus, having to adjust to a different position, while at the same time having to execute the drill. The ‘choreographed’ players had trained on the drill for three sessions of 15 minutes each, and had become familiar with its execution. The two forwards, with whom the test subject was required to execute the drill, were not permitted, at any time during the study, to communicate with the subject on any aspects concerning the execution of the drill.

To avoid the possibility of a familiarity confound, the training task was a novel drill that had not been encountered by any of the subjects in the past. The drill was designed to be particularly difficult for players to ‘guess’ at, in terms of its trajectory and sophistication. To achieve this goal, the drill incorporated elements that would be somewhat counter-intuitive for hockey players to follow, including elements of 'doubling back' and other less-conventional changes in direction.

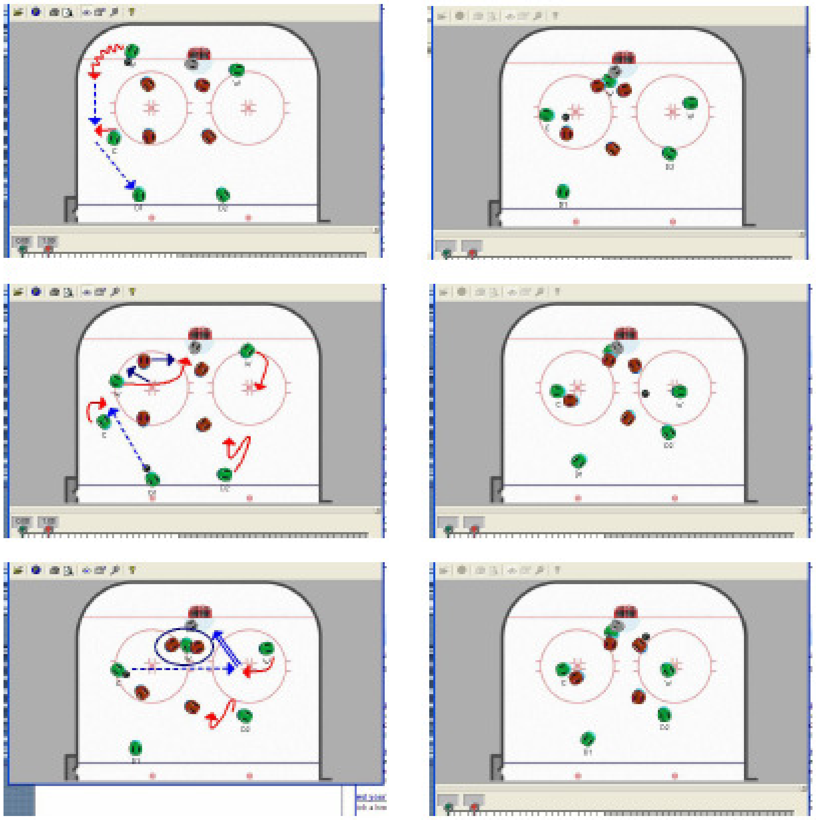


Figure 5.1 Traditional static diagrams (left) and time-lapsed animated view of same drill.

Four expert coaches were recruited to judge the accuracy of the subjects in executing the drill. The judges and the 'choreographed' players were all naïve as to which instructional group individual subjects were assigned. In order to obtain a baseline measurement of how the experimental drill should be properly executed, the judges previewed both the static and animated tools, and also viewed the 'choreographed' players performing the drill with high accuracy 10 times. Immediately after completing the instructional part of the session, the subjects were required to proceed to the ice and perform 10 trials with the ‘choreographed’ players. Between trials, players were permitted to review the drill on the medium it had originally been presented to them on. Upon completion of the 10 trials, the four judges independently assigned a score between 1 and 10 to the subject, based on how effectively they felt he understood, and executed the drill.

5.4 Results

Overall, the results indicate that players were able to learn, and execute the drill much more efficiently using the computer-animated chalk-board. On a Likert scale from 1 to 10, players’ mean performance scores were 3.63, using the static chalk-board, and 6.92, using the animated version. This indicates a performance increase of 90.6% for the animated learning tool over the static version. In order to confirm the significance of these findings, a Mann-Whitney U-test was undertaken on the data. Results showed a significant effect in the direction of the computer-animated learning tool ($U = 36$; $z = -2.8$; $p < .005$). See Appendix C for a complete breakdown of scoring by the judges.

In general, players had trouble grasping the flow of the play from the static diagram, although this was somewhat expected, in that the difficulty level of the drill was purposely set above that which most of the players had previously seen. Whereas, some players were better than others at understanding the static version, all players using this version of instruction misinterpreted, or missed, several key transitional points in the drill. Through informal interviews conducted post-trial, players using the static version indicated that they “*…had no idea where I was supposed to be when **** made his* *turn…I was behind but I think I was supposed to be ahead of him…"* and *"…**** was trying to pass the puck to me but I thought I had to cross instead…"* These comments are very representative of the general confusion that players experienced over the spatiotemporal aspects of the drill, as taught by the static tool.

In contrast, the difficulty level of the drill proved to be much less of a factor for the players who viewed the dynamic animated version of the drill. While participants using the static method took more time between trials to review the diagram, and most often continued to do this through to the last trial, with little benefit, participants using the dynamic method usually reviewed the animation only through the first few trials, taking time to pause and replay sections. Thereafter, they were able to execute most aspects of the drill, adding minor improvements to their performance as the trials progressed. Players using the animated tool told us *"I liked the pause thing…I could see where I had to be…and I knew I had to speed up to get in the right spot for the pass…"* and *"it took me a couple of tries…I had to go back and stop it where **** goes to the net…"*

5.5 Discussion

These results show the superior effectiveness of a dynamic, animated display over the traditional static version, for teaching patterns of play in ice hockey. But how are these results obtained? While the specific mechanisms of action are not known, we can speculate on what these might be, based on a general understanding of how humans cognitively process static and dynamic information. During the study, it was observed that, in learning the drill with the animated tool, players took advantage of the pause, rewind, and replay aspects of the tool. They told us that playing the drill from beginning to end was not as helpful as freezing the play at different points along its path. Presumably, this gave players an ability to situate themselves in the play at any point during its trajectory. This ability to stop the animation eliminates the need for the learner to hold earlier viewed portions of the play in working memory, as they would if the animation could not be stopped (Ainsworth and Van Labeke, 2004). Also, it has been suggested that dynamic processes are cognitively encoded by humans as a succession of static 'snapshots', taken at key junctures, and not as dynamic 'movies' (Hegarty, Kriz, and Cate, 2003; Lee, Klippel, and Tappe 2003).

It appears that the animated tool provides for an easier cognitive mapping between the information being learned and the real world it represents. It delivers, across the full time spectrum, the appropriate relational cues that a single static diagram of a drill cannot, and allows a player to more easily link these cues to the overall pattern of play. Players appear able, through a kind of cognitive simulation, to situate themselves, spatially and temporally, within the entire sequence of events. In contrast, the static model does not deliver these relational cues. It, instead, requires the learner to perform another layer of abstraction, in order to translate and then re-assemble the image, before cognitive simulation of the play is even possible. Further, in this situation the viewer can only speculate on, or infer, the relative positions of players at any specific point in time. Then, regardless of whether their inference is correct or not, they must hold this image in memory while assembling a subsequent 'inferred' relational picture at a further temporal point. As more of these 'snapshots' must be held in memory, the load placed on a player’s cognitive resources increases, as do the chances that earlier ‘snapshots’ may then be dropped from memory. Thus, the player must not only contend with translating a single image into a series of time-lapsed ‘snapshots’, he must expend additional cognitive resources to ‘infer’ the spatiotemporal interrelationships among players in each of these ‘snapshots’, and then hold each of these temporal ‘snapshots’ in memory in order to be able to mentally simulate the entire play sequence. The dynamic model reduces the level of cognitive load by off-loading the process of assembling, holding ‘snapshots’ in memory, and re-assembling.

With respect to whether the level of fidelity incorporated into the tool is adequate for transfer to occur, Williams and colleagues found that relational information between players, as well as their relative motion is much more important than postural cues and surface features for helping players understand patterns of play (Williams, Hodges, North, & Barton, 2006). Finally, it is reasonable to infer that viewing an animated play sequence presents a learning advantage over a static representation, through a visual presentation that shares aspects of motion with those of an actual on-ice demonstration.

6 CONCLUSIONS

6.1 Review

This research was guided by three questions. The first question asked: *Is there a theoretical framework that can effectively model perceptual-cognitive expertise in the hockey domain, and provide appropriate methodological tools for eliciting the elements of decision-making in a way that informs the instructional design process?* The *Recognition-Primed Decision Model (RPD)* was examined as a theoretical framework for characterizing decision-making and expertise in the domain of ice hockey. The RPD was originally developed to describe decision-making processes in naturalistic environments, characterized by uncertainty, and the requirement for rapid response (Klein, 1989). The model differentiates the decision-making practices employed by experts from those of non-experts. In the model, experts are said to utilize a pattern-matching strategy, where salient cues are rapidly extracted from an emerging situation and parsed for familiarity. This is described as the *recognition phase.* The model asserts that, because of a larger schema-base of domain-specific knowledge, experts are able to immediately return a response with the most probable chance of success. The model indicates that experts usually consider only one option during this process. Non-experts, on the other hand, are described as using a more rationalistic approach to decision-making, whereby a variety of options are considered at some length before a decision is made.

A study was conducted to elicit the decision-making strategies employed by expert and non-expert ice hockey players during competition. The RPD was used as a descriptive theoretical model for this work, and a methodological component of the model, *The Critical Decision Method (CDM),* was used as a data collection instrument. The CDM was originally designed as a type of cognitive task analysis tool that utilizes a set of probes and techniques targeted at eliciting the specific types of perceptual cues and cognitive strategies used by decision-makers in environments described by the RPD (Klein et al., 1989). Analysis of the data collected in the study showed: a) that the decision-making characteristics of expert and non-expert hockey players are consistent with those described by the RPD model of decision-making and, b) that the CDM presents an effective data collection methodology for uncovering the decision-making strategies, and specific cues and patterns, exploited by ice hockey players during competition.

The second question driving this research asked: *what ARE the underlying factors that influence the development of perceptual-cognitive decision-making skill in ice hockey?* The study (described above) found that the decision-making strategies of expert hockey players followed a feature-matching approach, where the familiarity of pertinent cues from the environment was used to facilitate a rapid, appropriate response. Experts used higher-order cognitive mechanisms like *estimation of outcome, assessment*, and *rehearsal*, among others, to guide their responses. These players relied on information such as the *current* and *historical* significance of *opposition player tendencies*, *point in time*, and *team strategy*, as well as visual cues like *spatial patterns of players, wrist movement,* and *eye movement.* In contrast, non-experts attended to less-relevant environmental features, and showed little evidence of higher-order feature/pattern-matching strategies. They seemed guided only by the information presented in the immediate visual landscape, and to that end, were inclined to attend to too much information at one time. Non-experts showed little indication of any monitoring or planning strategies. The types of visual cues they focused on were different from those parsed by experts, and tended to encompass mostly surface features like *sticks, skates, the puck, or the net.*

The final question guiding this research asked: *How can technology-based training solutions be designed to effectively enhance perceptual-cognitive decision-making skill in ice hockey?* Information gathered from study 1, on the cognitive and cue/pattern-recognition strategies employed by expert hockey players in decision-making, was used in the design of a multi-media learning prototype. The learning system was designed to target the *recognition* phase of expert decision-making, as outlined by the RPD. The learning environment focuses on training pattern and cue-recognition skills, at the perceptual and tactical levels of play. Instructional techniques of occlusion and guided discovery, established methods in the sports domain for training perceptual-cognitive expertise, were utilized in the design of the system.

The effectiveness of the system to transfer learning was investigated through a second study. A major component of the system, an animated coach's chalk-board, was tested against the traditional static version of the tool for it's effectiveness in conveying a sophisticated tactical play to expert hockey players. The findings showed that the tool was superior to the traditional method for affecting transfer to the field.

6.2 Limitations and future research

There were several limitations evident from this work. In study 1 it was observed that, although the elite players were usually able to describe what they were visually attending to, and thinking about, during the lead-up to their decision response, they seemed unable to describe *how* they executed the response. Their descriptions were at times more generic, than specific to the decision point being discussed. There is some indication in the literature that experts have trouble describing these processes because of their highly proceduralized nature, and the fact that these skills are not, in effect, under conscious control during execution (Beilock & Carr, 2001). Experts rely on a faster, less intrusive (and thus less available), LTWM retrieval process, while non-experts' decision-making responses are not yet automated, and are therefore 'constructed on the fly' from a more declarative, and conscious, type of procedure. In study 1, corroboratory evidence, such as eye-tracking, would have been helpful in further confirming and the detailed elements that make up the decision-making process of experts.

There is also a caveat that must be attached to the results from study 2. A short time after this study was completed there was an indication of some retention problems with the group who had trained on the animated tool. Although these anecdotes were not widespread it is important to discuss them with respect to any future studies in this area. No retention tests were included in the current study so it is difficult to quantify this issue. Some players who had used the tool said that, on the day of the study they were able to quickly replicate the pattern shown by the animated tool, but that it 'left them' within a day or two. While it is difficult to speculate on what might be happening in this situation there are some indications in the literature that dynamic representations may produce a less-robust encoding of information. The key may lie in the degree to which the viewer is cognitively active in the learning process. Hegarty and colleagues found that when learners were required to learn from text and static diagrams they tended to mentally animate the images (Hegarty, Kriz, & Cate, 2003). Hegarty speculates that this process may produce a "more enduring understanding" than simply having an external animation directed at one (Hegarty, 2004). Ironically, then, it may be that, although the dynamic tool was able to present a more realistic portrayal of the event, and off-load much of the heavy cognitive demands of learning the play, producing a better initial understanding, this very reduction in cognitive activation may have hindered the depth of encoding required for long-term retention. To further complicate matters, Hegarty was comparing static displays to *non-interactive* dynamic displays. In our case, the dynamic tool is interactive, allowing the player to pause, rewind, and repay the sequence. We might speculate then, that a *non-interactive* animated chalk-board might produce even greater retention problems. To attempt to answer these questions it would be prudent to pursue a retention protocol as part of any future work in this area.

There are several areas of study that may be generated out of this research. First, the *Recognition-Primed Decision Model* and the *Critical Decision Method* proved to be valuable tools for defining and understanding the characteristics of experts (and by contrast, non-experts) in ice hockey. It would be interesting to use the CDM to assess the decision-making characteristics of a group of players whose talent level is not known, or undefined. In this case, the framework could be tested for validity as a talent identification, or measuring, tool. A valid model of this sort would be of great benefit to coaches and management both in the hockey world and beyond. The use of eye-tracking, within the RPD framework, might also prove helpful in corroborating the findings from study 1.

Finally, there is still very little known about the neural underpinnings involved in learning from static versus dynamic displays. A more integrated research agenda that brings together perceptual-cognitive theory, visual science and neuroscience is warranted, in order to understand how best to present the important patterns and cues that athletes rely on to make decisions.

6.3 Contribution

The research described here provides contributions in both theoretical and applied areas. First, a novel use of the *Recognition-Primed Decision Model* is presented, which utilizes the model as a theoretical framework for describing the decision-making mechanisms of expert and non-expert hockey players. Second, the *Critical Decision Method*, which is specifically designed to investigate decision-making environments that fit the RPD definition, has been modified for use as a new data collection methodology in the sports domain. These tools also show promise as instruments for talent identification and player evaluation. Finally, a new taxonomy has been articulated, which describes the decision-making elements used by hockey players in competition. These underpinnings provide a new foundation for coaches and developers to use in designing training solutions in hockey. To that end, they have been used here to develop a multi-media prototype to train perceptual-cognitive skill in ice hockey.

APPENDICES

Appendix A: Cognitive Probes

Interview questions (probes) for hockey players –

General questions:

Goal specification
What were your specific goals during this game?
What were your specific goals during this shift?
How did goals alter with the situation?
How did you re-establish goals?

Cue identification
What features were you looking at when you formulated your decision?
How did you know that you needed to make the decision?
How did you know when to make the decision?

Expectancy
Were you expecting to make this type of decision it this point?
Describe how this affected your decision-making process.

Conceptual model
Are there any situations in which your decision would have turned out differently?
Describe the nature of these situations and the characteristics that would have changed the outcome of your decision.

Influence of uncertainty
At any stage, were you uncertain about either the reliability or the relevance of the information that you had available?
At any stage, were you uncertain about the appropriateness of the decision?

Information integration
What factors affected your decision?
What was the most important piece of information that you used to formulate the decision?

Situation awareness
What information did you have available to you/use at the time of the decision?
What information did you use in recognizing the situation ⁄ making the decision?
What options were open to you at this moment?

Situation assessment
Did you use all the information available to you when formulating the decision?

Was there any additional information that you might have used to assist in the formulation of the decision?

Strategy/Planning
How did you arrive at your chosen course of action?
What strategy did you use in reaching your decision?

Options
Were there any other alternatives available to you other than the decision that you made?
Why were these alternatives considered inappropriate?
How did you decide which option to take?

Decision blocking stress
Was there any stage during the decision-making process in which you found it difficult to process and integrate the information available?
Describe precisely the nature of this situation.

Basis of choice
Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision successfully?
Do you think that anyone else would be able to use this rule successfully? Why/Why not?

Analogy/generalization
Were you at any time, reminded of previous experiences in which a *similar* decision was made?
Were you at any time, reminded of previous experiences in which a *different* decision was made?
Did you have any rules of thumb to use in this situation?
How did you know they were appropriate?

Simulation/rehearsal
What sort of projections were you making into the future / for what sort of things would you have to be anticipating?

Examples of Hockey-specific questions:

Can you describe some of the 'tricks' you've learned to use to gain an advantage over the opposition? Why do you think these techniques work? What do they allow you to do?

Can you compare situations where you will try a particular manoeuvre and others where you will not? Can you describe the different circumstances to me?

In general, can you tell me the first thing you consider when deciding how to react to an oncoming opposition player?

After viewing this current play on the video, can you discuss with me the factors you used in deciding to pass/shoot/check? And at what point? Can you give an indication of what was in your field of vision at that time? Were you aware of players around you? Which ones?

When you approached number xx to check him, as shown here on the video, what information were you using to decide how to approach him? What areas were you looking at?

When controlling the puck in this clip, what information did you use in deciding when to pass/shoot/continue skating?

Were you aware that number xx was in the position shown here on the video when you were in your position?

Did you know you had an opportunity at this point to pass/shoot/skate? Why did you choose the option you did?

Appendix B: Study 1 - Coded decision-making categories

118 decision points coded (80 elite (n=23) / 38 intermediate (n=14)

	Players	
	Elite	**Intermed**
1. Cognitive processes		
Goals		
next shift	14	3
game	10	2
Assessment		
past	10	4
current game	12	1
previous games	8	3
Planning		
< seconds	2	0
seconds	28	5
minutes	14	2
game	11	1
Reviewing decisions/Retrospection/reflection	11	2
Simulate/visualize future state	27	1
Situational awareness	16	3
Considering options/comparing	4	14
Flexibility (responding to change)	9	1
Establishing a shared understanding	5	1
Information seeking/gathering	15	3
Understanding significance of information/situation	21	2
Trial-and-error	5	17
Estimation of outcome/Assigning situational probability	14	2
Examining familiarty of information/situation	25	5
Understanding role	22	4
Uncertainty	8	21
Totals	291	97

2. Cues Utilized

Pattern recognition

make-up of players on the ice		18	2
Player spatial patterns		16	5
Relational position to teammates		21	6
	Totals	55	13

Cue recognition

Hips/thighs		26	1
Shoulders		2	8
legs		2	10
arms		4	6
chest		31	2
Wrist		24	0
Head		7	3
Eyes		28	9
Skates		5	10
Stick		7	8
Puck		6	11
Net		12	6
	Totals	154	74

3. Contextual factors utilized

point in time		12	2
face-off location		14	1
opposition player performance		10	2
opposition team performance		8	1
powerplay/PK		13	1
player attributes/tendencies		14	2
team strategy/tactics			
- short-term		11	2
- long-term		8	1
team goals			
- short-term		12	2
- long-term		11	3
	Totals	113	17
	Grand tot	613	201

Appendix C: Study 2 – Judges Scores

Player	static score	judges scores - static method				
		judge a	judge b	judge c	judge d	avg/player static
1	3.25	3	3	3	4	3.25
2	4.75	4	4	6	5	4.75
3	4.5	5	4	4	5	4.5
4	2.5	3	2	3	2	2.5
5	3.25	3	1	5	4	3.25
6	3.5	3	3	4	4	3.5
avg - static method	3.625	3.5	2.833333	4.166667	4	3.625

	dynamic score	judges scores - dynamic method				
		judge a	judge b	judge c	judge d	avg/player dynamic
7	7	8	5	9	6	7
8	8	8	6	10	8	8
9	7.5	7	6	8	9	7.5
10	6.5	6	8	7	5	6.5
11	6.75	7	6	7	7	6.75
12	5.75	8	4	6	5	5.75
avg - dynamic method	6.916667	7.333333	5.833333	7.833333	6.666667	6.9166667

Judges scores	
static	dynamic
3	8
4	8
5	7
3	6
3	7
3	8
3	5
4	6
4	6
2	8
1	6
3	4
3	9
6	10
4	8
3	7
5	7
4	6
4	6
5	8
5	9
2	5
4	7
4	5

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