Cognitive Model Supported Tactical Training Simulation

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ABSTRACT: *Simulation-based tactical training can be made more effective by using cognitive software agents to play key roles (e.g. team mate, adversaries, instructor). Due to the dynamic and complex nature of military tactics, it is hard to create agents that behave realistically and support the training leader in keeping control over the scenario. For successful use in training, agents should provide trainees with opportunities to achieve the learning objectives in both simple and complex scenarios. We developed such a cognitive agent, playing the enemy force in a tactical training scenario. The cognitive agent was then integrated in a training simulation and tested with naval officers. Results show that the agent successfully supported achievement of the learning goals.*

1. Introduction

One complicating characteristic of tactical command and control is that there is often uncertainty about the intentions, capabilities and strategies of the parties involved. In such situations, there is no single "right" way to accomplish the task (Hutchins, Kemple, Porter, & Sovereign, 1999). There usually exist more than one good solution for a problem, depending upon the assumptions and inferences the decision maker is willing to accept. To make the issue even more complex: task achievement in real life is not solely determined by human performance, but is also affected by equipment (mal)functioning, surrounding environment, and luck (Smith-Jentsch, Johnston, & Payne, 1998). This absence of unequivocal relationships between the problem context, the interpretation by the decision maker, the chosen actions and the outcomes makes it hard to develop and provide training in tactical command. Operational scenarios are not suitable because their complex and unpredictable nature is in conflict with the fundamental training requirement of having control over task content (Fowlkes, Dwyer, Oser, & Salas, 1998). Control is necessary to enable the effective acquisition of knowledge about relationships between processes and outcomes. To achieve this control, military training schools nowadays need Subject Matter Experts (SMEs). SMEs have the expertise to take the situational context into account and use this understanding to evaluate (on-line) the appropriateness of trainee behavior. They can also assess whether the training scenario develops in the intended direction. Because of these qualities, SMEs are used in tactical training as scenario leader, as instructor, and as role player (e.g. team mate, opposing forces, own forces). SMEs make it possible to deliver tactical training scenario that represent reality in terms of dynamics and complexity, whilst maintaining a high level of control. However, the use of SMEs has disadvantages as well. One problem is that experts often evaluate trainee performance intuitively, without being able to precisely point out which cues (or absence of cues) they use for diagnosing trainee behavior. This lack of meta-cognitive awareness may be the cause of another problem for training, namely that SMEs do differ in opinion on what is to be considered as appropriate and inappropriate behavior. It is clear that this hampers transparency of performance measurement and feedback. Finally, the need for SMEs to deliver training elevates costs of training and requires high organizational and logistic efforts.

Automation may be the solution for these problems. If we can develop software agents that in training scenarios produce the behavior of the individual or entity that they represent, we would be able to make training more traceable, more systematic, and more cost-efficient. One solution would be to develop agents using Finite State Machines, specifying appropriate behavior for all possible states that may occur during a scenario. However, for tactical command this is considered not to be a feasible approach, as in even fairly simple scenarios the number of states tends to be very high (Klein, 1998). A more promising approach is to develop agents using cognitive models (Zachary, Ryder & Hicinbothom, 1998). A

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cognitive model represents the knowledge and cognitive processes of an individual or entity in a certain domain, task or scenario. This representation needs to be so specific that, when provided with input, the cognitive model produces realistic behavior as output. There is a growing conviction that cognitive modeling be can used successfully to improve tactical training (Pew & Mavor, 1998). Cognitive models have been developed for creating agents that support or replace the instructor (Heinze, Lloyd, Goss, & Pearce, 1999), a team mate (Rickel & Johnson, 1998), and enemy forces (Wray & Laird, 2002). The focus of the majority of these studies was to develop and test methods and architectures enabling the construction of cognitive models. This has produced a substantial number of computational cognitive architectures, such as ACT-R, SOAR, EPIC, and COGNET to name a few. For the Royal Netherlands Navy (RNLN) we zero in on these results. The focus is not so much on developing new architectures, but on how we can use cognitive architectures and cognitive models to open up new opportunities for tactical training. This paper reports a study on the development, deployment, and validation of a cognitive agent representing the enemy forces in a simulation-based tactical training scenario.

2. The present study

The present study is conducted in the domain of anti-surface warfare (ASuW). Simulation-based training constitutes a major component in the training of naval-officers. The simulator in use consists of a scenario control station and six cubicles. The control station is manned by the scenario leader and by several SMEs playing the opponent forces and other own forces. Cubicles are equipped with computers simulating the CIC of a frigate. Ordinarily, a cubicle is manned by pairs of trainees and an evaluator. One trainee plays the role of Command Central Officer (CCO), the other of his assistant. The evaluator in the cubicle evaluates task and team behavior (e.g. communication, coordination, leadership etc). The scenario leader starts a tactical scenario; the trainee-teams react to the events. The training staff follows the course of events for each trainee-team and provides those responses of own and enemy forces that are necessary to keep the scenario on track of the learning goals. This training setup has several practical and didactical drawbacks. First, this type of training requires a lot of personnel. Sometimes, the ratio trainee-instructor can be as high as 1:1. Secondly, the training staff needs to monitor several trainee-teams simultaneously, making it hard to stay aware what is going on in a particular team. Thirdly, valuable training time of trainees is used to play the role of an assistant rather than that of a CCO (for which they are in training).

In order to investigate if and how cognitive agents can improve the efficacy and efficiency of such training, we conducted a proof-of-principle study. We developed a cognitive agent for playing the role of the enemy forces in a particular training scenario. Such a Cognitive Model Supported Tactical Training (hereafter abbreviated as CMSTT) can be considered as an integrated system of learning objectives, scenario, agent and simulation. The functional requirements of such a system need to take the interrelationships between its constituent components into account. We used the following procedure:

1. Identifying and selecting appropriate training objectives
2. Designing a training scenario enabling the achievement of the learning goals
3. Performing cognitive task analysis to identify the opponents' knowledge and strategies
4. Identifying instructional strategies. Formalizing this into a cognitive model
5. Implementation of the cognitive model into a computational cognitive agent
6. Implementation of scenario in simulation software; integrate agent and simulation
7. Test the resulting CMSTT using naïve navy officers

We will now elaborate on each of the aforementioned components. Each section starts off with requirements in a global sense, followed by the way we worked it out in this study. All activities were carried out in close collaboration with officers of the operational school of the Royal Netherlands Navy.

3. The learning objectives

The development of scenario-based tactical training starts with the formulation of learning objectives. In a broad sense, the goal of tactical training is to learn and practice the cognitive activities that are fundamental to adequate tactical command. The problem is that these activities take place inside the head of a person, usually unavailable for observation (e.g. memory retrieval, reasoning). Therefore, it is necessary to define the learning objectives in terms of observable activities that relate to the activities of interest. For instance: "trainee re-orders his task group formation to obtain information that would otherwise remain unknown". In general, learning goals should focus on those activities that are necessary to (a) gain and improve insight in the exact nature of the tactical situation at hand, and (b) to examine the opportunities and restrictions of different tactical plans. Learning objectives need to be formulated in such a fashion that they can be trained in both simple and complex scenarios. This allows for flexible development of training simulations. Relatively simple simulations can be used when there is little time or few resources; more advanced simulations (e.g. multiple agents, more (aspects of) entities simulated) can be used to increase realism. In order to determine the learning objectives for the present study, we interviewed instructors of the Operational School. It is clear that the training of CCOs consist of many learning objectives. The purpose of this part of the study was to select a piece of navy warfare, and to identify those learning objectives that relate to the behavior of enemy forces. In order to do this, we conducted a structured interview with instructors of the Anti Surface Warfare (ASuW) group. This resulted in a list of learning objectives. From this list, the following two were selected: (a) when to split up a task group of ships in order to gather information for threat assessment, and (b) how to make an optimal selection and formation of ships based on the task, the capabilities and availability of each ship. These objectives can be achieved using a relatively simple scenario that is purely surface warfare. There is no need (nor any barrier) to set up more realistic and complex training scenarios (e.g. with multiple forms of warfare) for these learning objectives.

4. The scenario

A tactical training scenario consists of a mission, a situation description and anticipated events. The mission is described in terms of operational goals. The situation is described in terms of environmental conditions, enemy intent and capacities, intelligence information, logistic and organizational constraints, and other relevant types of information. A scenario contains opportunities for event to take place. An event can be defined as a critical moment in task execution, marked by (the absence of) a significant cue, requiring a response by the trainee as formulated in the learning goals and resulting in reactions of other players. Scenarios must be constructed in such a fashion that trainees can achieve the specific learning objective. However, at any point during the scenario, trainees may or may not perform the desired behavior. As the actions of the trainee obviously influence the course of the scenario, it is difficult to plan the training fully ahead. A scenario can offer the opportunity for these situations to occur, but whether they do depends on the approach of the trainee.

For the present study, the following scenario was constructed in collaboration with an RNLN instructor: The trainee plays the role of commander of a task group consisting of a Amphibious Transport Dock (the High Value Unit, or HVU) escorted by 4 frigates. His task is to bring the HVU to its destination within a tight timeframe. The commander has intelligence information about the type and number of enemy forces present in the area (see Figure 1 for a map of the situation). The information provided should lead to the conclusion that a detour in order to escape the enemy is not possible. The trainee has to formulate a plan how to clear the fastest route for the HVU and executes that plan in an interactive simulation. One learning objective is achieved when the trainee takes all information into account and comes to the conclusion that information concerning the location of the opponent can best be gained by splitting up the task group. The second learning objective is achieved when the trainee takes the specific capabilities of the different frigates into account to form adequate picket and main group.

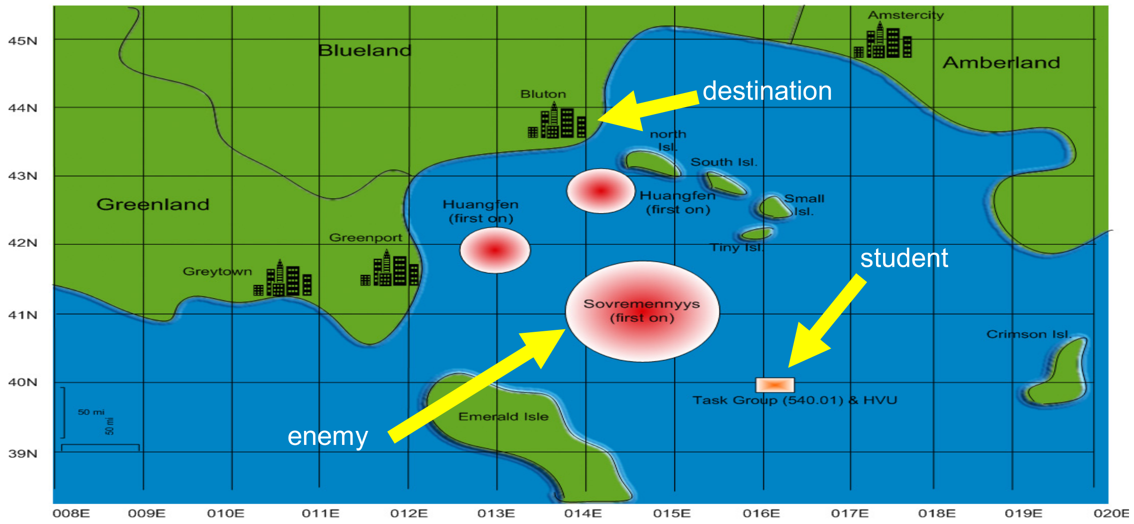

Figure 1. Geographical map of the scenario, showing the position of the ships of the trainee (task group), the two ships of the opponent (sovremennyys) and the destination of the HVU.

5. The agent

An agent that functions as the opponent in this scenario needs to capture the essence of what makes human role players so adept at providing appropriate behavior for training. It needs to generate proactive behavior in order to realistically pursue tactical and didactical goals. Furthermore, the agent does this in an unpredictable environment. After all, the trainee may at any time decide to do something unexpected. This asks for an agent that has a robust way to assess situations in order to generate appropriate behavior. Those generated decisions also need to stand the test of expert scrutiny. This will only be possible if experts can recognize common tactical knowledge in the agents' behavior. Finally, the agent will need to do all this in a human-like manner. This requires that the agent incorporates considerations that are representative of those that humans have when formulating and executing a tactical plan.

For the present study we developed an agent meeting the requirements above. The agent was named TACOP, standing for TActical COgnitive OPponent.

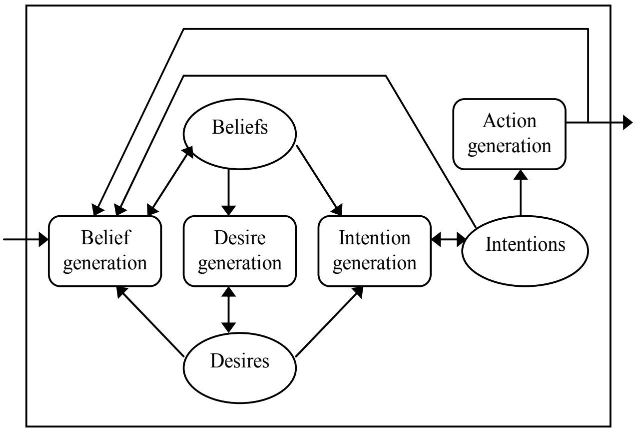

Figure 2. Scheme of TACOP model.

A Cognitive Task Analysis (CTA) was carried out in order to identify TACOP's knowledge and strategies (see Schraagen, Chipman & Shalin (2000) for an overview of CTA techniques). Key events in the scenario were identified. Expert instructors were asked to take the perspective of the enemy in the scenario, and were interviewed thoroughly about each event. The goal of the interview was to identify which cues the expert considers as relevant and which are not; what knowledge they bring in to assess the nature of the situation, what assumptions they make and why; what assumptions they reject and why, which strategies they consider appropriate and which are inappropriate. The results were coded in terms of knowledge, beliefs and desires. Based on this information a general scheme of cognition was conceived for the cognitive model (see Figure 2). This scheme, based on the BDI model (Georgeff & Lansky, 1987), allows opponent behavior to be autonomous and proactive. The scheme was implemented in the CogNet environment (Zachary, Mentec, & Ryder, 1996).

Instructors are not only subject matter experts, they are also familiar with typical errors of trainees. They know the gaps in tactical knowledge, what kind of erroneous assumptions trainees tend to make, and so on. In the interview we asked the instructors to explore the consequences of these knowledge gaps and errors for this particular scenario. Together we identified what actions of TACOP would make the consequences clear to the trainees. This information on typical errors and associated actions was incorporated into the cognitive model.

An example from the scenario illustrates how this works out. If the trainee decides to hold the ships of his task group together (which experts consider as inappropriate for this situation) rather than splitting them, the task group will pass within radar range of the vessels controlled by TACOP. TACOP will then detect the radar of the HVU and will attempt to attack and destroy the HVU. In terms of the model: TACOP *desires* to find the HVU in order to destroy it and is searching for it. A *belief* is generated that the HVU is close due to the radar signal. A *desire* to attack the ship from which the signal originates is generated. The *intentions* to change course, turn on radar and prepare to attack are generated and result in the corresponding *actions*. However, if the trainee chooses to split up the task group and form one or more scouting escorts, then TACOP will encounter these scouts and consequently generates different *desires* (to avoid the scouts) and different *intentions* (circumnavigate). This demonstrates the proactive capabilities of the model, the manner in which it can deal with unexpected situations and its correspondence to human behavior (because the behavior is derived from information about the cognitive activity of an instructor during an exercise).

6. The simulation

The properties and effectiveness of a cognitive agent can only be studied in an environment. An agent needs to be able to "perceive" the environment, and actions of the agent have to affect it. For training purposes, agents are used in simulated environments. The simulation provides a representation of the physical aspects of the environment. For example: terrain and entities (including among others

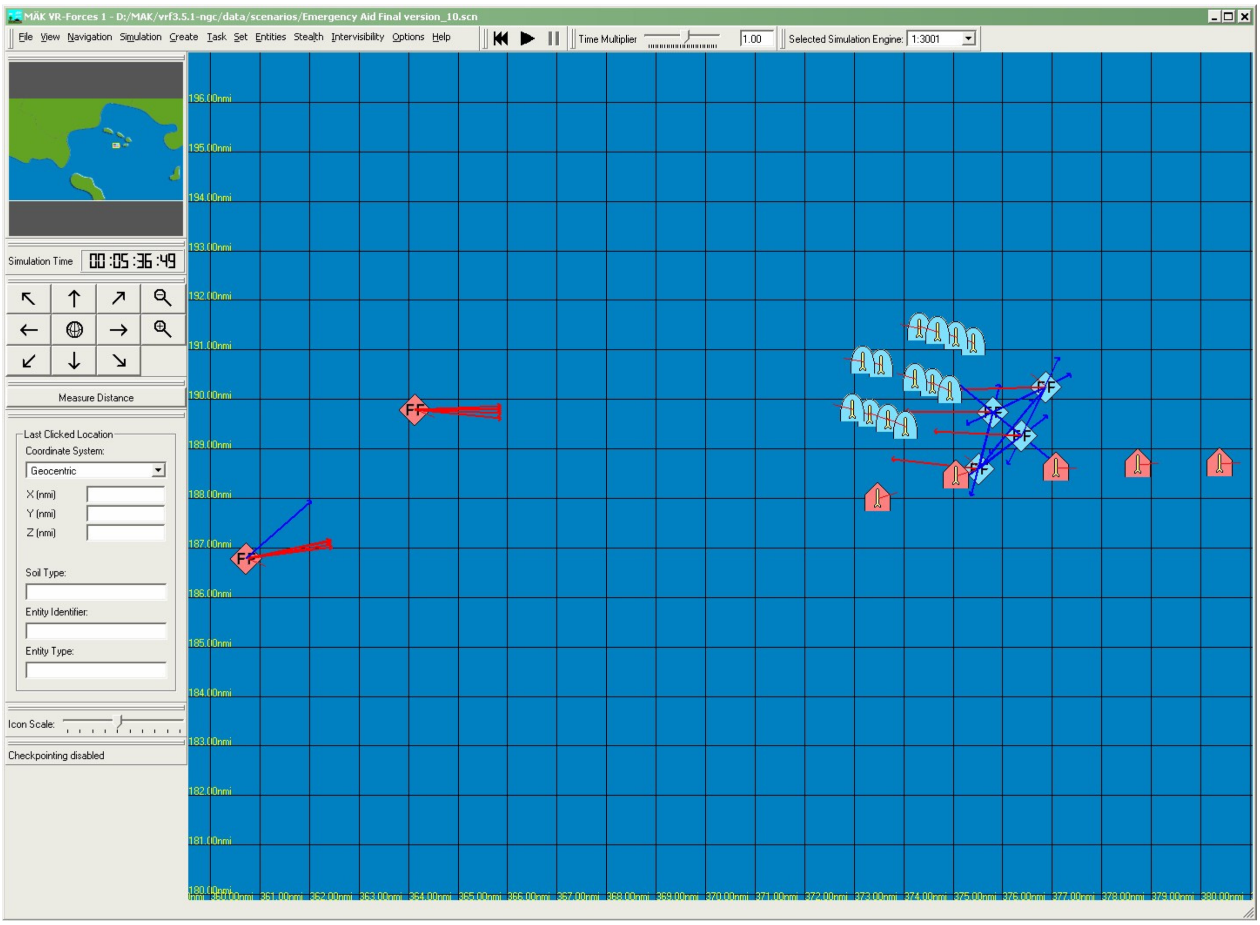

Figure 3. Screenshot of the simulation showing an engagement between the trainee and the TACOP model.

weapons, sensors, motion, damage, and inventory). Both the trainee and the opponent agent form a part of each others environment. The simulation forms the shared environment of both.

A simulation was developed (see Figure 3). It consists of five computer programs (see figure 4) and two computers connected by a network. The five programs are: a simulation server application, a network routing application, a trainee application, an exercise supervisor application and an agent application. One computer is used as a trainee console and one computer is used as a server. Network communication occurs using a simulation network protocol called High Level Architecture (HLA). This protocol allows simulation software to effectively exchange simulation information.

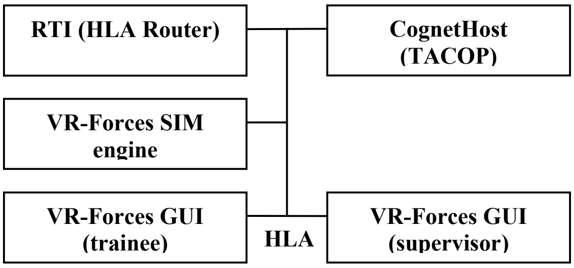

Figure 4. Applications used for training simulation**.**

Commercial off-the-Shelf (COTS) software was used to construct the training simulation. Both the simulation software (VR-Forces[1]) and cognitive modeling software (CogNet[2]) were modified or extended for this study. Among others, the following modifications to the existing software were made:

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[1] VR-Forces is product of MÄK Technologies, see http://www.mak.com

[2] CogNet is a product of CHI Systems, see http://www.chisystems.com/products/products_igen.htm

- A custom version of the simulation server was developed that allows more appropriate sensors to be modeled.
- The trainee application was enhanced with tools and cues that the trainee needs to perform the exercise.
- Tools to better control the ships of the simulation were added to the supervisor software.

The cognitive modeling software and simulation software were integrated for use in the training.

7. Validation

The aforementioned components were integrated in a fully-functional prototype of Cognitive Model Supported Tactical Training. In order to evaluate this prototype, two ASuW-officers in training to be instructor, were asked to participate. The evaluation was done in three successive phases:

- Perform the exercise as trainee while thinking aloud
- Fill out a questionnaire after scenario completion
- Participate in an interview afterwards

The think-aloud protocols clearly indicate that the opponent agent triggered considerations about the issues formulated in the training objectives. Thus, the instructors were evaluating the knowledge and strategies that they were utilizing during the session. The results of the questionnaire show that the participating officers are positive of the potential learning value of this type of training. They expressed their high expectations of this technology for the (near) future. They also provided suggestions for improvement. The interview was structured around three themes: instructional value of the agent, tactical representatively of the agent, and requirements for simulation fidelity. Both participants felt that the actions of the opponent (generated by the agent) caused them to reflect upon their choices and to consider alternative tactical strategies. The participants agreed and responded positively on questions about tactical representatively: all actions taken by the agents were considered as tactically logical. Finally, although the environment and entities were modeled on a functional level only, participants evaluated the necessary requirements for simulation fidelity satisfied. They indicated that the simulation contained the relevant aspects of the tactical situation to perform the assignment.

8. Discussion

The study resulted in a CMSTT that allows participants of the RNLN to perform a tactical assignment in a functionally realistic virtual environment. This environment is open because participants (agent and trainee) were free to develop their own tactics and pursue their own line of reasoning. The environment is complex because participants had to manage information about ships, systems, sensors as well as the decisions of their opponent. The environment is dynamic because the actual state of the tactical situation continuously changed as function of decisions. Thus, the training recreates the conditions in which naval officers make decisions during surface warfare.

In the present study we interviewed experts to develop a cognitive opponent model specifically tailored to this scenario. The model covers all states of the paths through the scenario anticipated by the interviewed experts. It is demonstrated that TACOP produces tactically and didactically sound behavior for all those states. However, as argued before, the variations of paths through a tactical scenario are virtually endless. TACOP is designed in such a way that it always generates a response. Whether the responses in states yet unforeseen by the experts, are also tactically representative, requires a more thorough systematic evaluation than performed in this study. Such an evaluation should take the purpose of the training into consideration. The criterion for representativity is dependent on this purpose. Let us use an example to illustrate this point. When in charge of tactical command, CCOs are highly dependent on their assistants. Among others, the assistants provide essential information, make checks for the CCO and monitor equipment readiness. One important learning objective of the CCO is therefore to keep an eye on the assistant's task performance and to correct any errors. However, in normal life, assistants do their job accurately: they make few errors. If we would develop a highly representative cognitive agent of the assistant, this agent would not provide the CCO with many opportunities to practice error detection and correction. However, if we would develop an agent that makes unrealistic number of errors, this agent would provide the CCO with plenty practice opportunities. In conclusion, an agent must be representative of an assistant, however for the purpose of training the assistant is augmented with erroneous behavior. A representative agent performs the behavior of the assistant including augmented behavior.

Investigating the use of a cognitive agent in surface warfare follows from a more general challenge, namely the training of open cognitive tasks in complex situations. In order to develop realistic training, the most common approach is to use domain experts and fellow-trainees to play the key entities in such training. The result of this study shows that a cognitive model can also successfully play a key role in such training. The present study provides no answer to the question whether this results in better or worse training than the current way of training. Training effectiveness of neither the current way of training nor the model supported training has been measured. Such an investigation should consider the distinction that needs to be made between internal validity and external validity. Internal validity corresponds to the measure of contribution of the training to the trainee achieving the learning objectives (Does the training achieve what was intended?). External validity corresponds to how well learnt skills and strategies are applied during performance in the real world. A CMSTT offers the means to investigate these questions concerning training with cognitive models. The proof of concept provides an experimental environment in which different forms of simulation-based tactical training can be compared. Investigators are now able to compare current training methods with a CMSTT. The experimental environment allows investigation into the influence of certain aspects of a cognitive model on training effectiveness. Different uses of cognitive models can be explored as well (team members, instructors, coaches and neutral players).

It is important to study cognitive modeling for a specific purpose (e.g. Chandrasekaran & Josephson, 1999; Pew & Mavor, 1998). We will research modeling methods to efficiently create dedicated models. In order to achieve this, subsequent studies will investigate invariant mechanisms in the agent model that may be exploited.

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