Intelligent Tutoring Agent for Settlers of Catan

Jeroen Geuze[a,†] Egon L. van den Broek[a,b,†]

[a] *Nijmegen Institute for Cognition and Information, Radboud University Nijmegen*
P.O.Box 9104 6500 HE Nijmegen, The Netherlands
geuze.j@gmail.com
[b] *Center for Telematics and Information Technology, University of Twente*
P.O.Box 217, 7500 AE Enschede, The Netherlands
e.l.vandenbroek@utwente.nl

Abstract

An Intelligent Tutoring Agent (ITA) for the board game Settlers of Catan (SoC) is introduced. It uses CLIPS knowledge bases, connected by JCLIPS to a JAVA implementation of SoC. It is founded on a new theoretical framework that describes the development of negotiation skills in children. Using this framework, the ITA helps children in developing negotiation skills through play, which makes it unique in its kind.

1 Introduction

The concept of learning by playing has proved its use for virtually all species, including man kind. Playing and games are even considered as essential for human development [3]. Consequently, various disciplines have included games as a field of research [5], among which AI. However, especially for AI, mostly board games are topic of research; e.g., Chess, Checkers, and Go [5]. This paper issues another type of board game: Settlers of Catan (SoC) [10]; Figure 1 provides a brief description of the game. We choose SoC since we were interested in the development of negotiation processes with children and for playing SoC, negotiation is one of the most important skills. Another advantage of SoC is its popularity.

This paper introduces an Intelligent Tutoring Agent (ITA) that helps children understand the negotiation processes through playing SoC. For the latter purpose, we first developed a theoretical framework, founded on 1) Piaget's theory of child development and 2) adult negotiation strategies, as will be described in Section 2. Subsequently, the expert system of the agent founded on the theoretical framework is documented in Section 3. The development of the ITA itself is described in Section 4. The paper ends with a Discussion (Section 5) in which we reflect upon the work presented.

2 Theoretical Framework

The amount of research done on either children and board games or on children and negotiation is very limited [5]. Therefore, we choose to develop a new theoretical framework founded on two theories: 1) the child development theory of Piaget [7] and 2) Thompson and Hastie's [12] theory on negotiation between adults. The combination of the latter theories, enabled us to determine the initial level of understanding of the negotiation process in children. We will now first briefly introduce both theories and derive some general cognitive notions. Subsequently, the general cognitive notions are related to the stages Piaget distincts. Knowledge gathered through the latter three steps is merged to a new theoretical framework.

[†] At the time this research was conducted, both authors were affiliated with the Department of Artificial Intelligence, Division of Mathematics and Computer Science, Vrije Universiteit Amsterdam.

The players in the game represent the eponymous Settlers, establishing a colony on the previously uninhabited Island of Catan. The island itself is laid out randomly at the beginning of each game from terrain hexes depicting mountains, plains, woods, etc. The settlements founded by the players provide their owners with natural resources dependent on the adjacent terrain, and dependent on die rolls each turn. These natural resources are used for activities such as building roads, upgrading settlements to cities, and purchasing development cards which represent a variety of advances toward civilization. The winner is the first player to accumulate ten victory points via these activities.

Players are allowed to trade among each other the resources they have produced, and to trade "off the island" for a hefty price. It is difficult for any one player to produce all the resources necessary for progress, so astute trading is the strategic heart of the game. Player interaction is further complicated by the presence of a robber, which is used to steal from other players and hinder their production of resources. There is no combat. Apart from the robber and refusal to trade there is no way to harm other players.

Source: `http://www.absoluteastronomy.com/encyclopedia/S/Se/Settlers_of_Catan.htm`

Figure 1: Brief description of the game Settlers of Catan (SoC).

Piaget distinct four stages of cognitive development [7]:

1. Sensory-motor stage (0-2 years): Characterized by the development of sensor and motor reactions.
2. Pre-operational stage (2-7 years): Characterized by egocentrism, rigidity of thought, semi-logical reasoning, and limited social cognition.
3. Concrete operational stage (7-11 years): The development of the operation: an internalized mental action that is part of an organized structure. Consequently, the child starts to think in terms of operations.
4. The formal operational period (11-15 years): The ability to generate hypotheses about the logical relations between the outcomes of concrete operations develops.

However, the theory of Piaget does not discuss negotiation. Hence, for the latter purpose another theory, that of Thompson and Hastie was taken into account.

According to Thompson and Hastie [12], six judgments can be distinguished in negotiating:

1. Judgments of the Other Party; e.g., the other party's strength or firmness, competitiveness, and fairness.
2. Judgments of the Self that involve the negotiator's tastes, values, and preferences.
3. Interpersonal Judgments of Utilities: the negotiator's perception of his own utilities, of the utilities of the other party, and the amount of resources that will be negotiated about.
4. Judgments of Offers and Counter-offers.
5. Judgments of Outcomes: to determine the value of a solution and, consequently, the satisfaction.
6. Judgments of Negotiation Process concern the fairness and satisfaction of the whole negotiation process. They include judgments about the rules, fair play, norms, etc.

The general cognitive aspects were determined taking the following aspects into consideration: 1) They should be based on the judgments put forward by Thompson and Hastie [12], 2) they should be applicable on the domain of Settlers of Catan and be generalizable to a broader domain, and 3) they should be able to match with the stage theory of child development to tailor these aspects to children. The general cognitive aspects and the judgments they are based upon are summarized in Table 1.

The fourth and last step in setting up the theoretical framework was to denote for each stage defined by Piaget [7], whether or not each of the general cognitive aspects is already present in children in that stage of development. Let us illustrate the latter by sketching the decision process for the *Feeling for utility to other party* aspect. In the pre-operational stage, this aspect is not yet developed since children have a limited

Table 1: Cognitive aspects and corresponding judgments from which they were inferred from.

Cognitive Aspect	Judgment(s)
Feeling for numbers	4
Feeling for fairness	4
Feeling for utility to self	2, 3, 4, 5
Feeling for utility to other party	1, 3, 4, 5
Ability to keep one's goal in mind	
Ability to hypothesize	4, 5

social cognition and are egocentric. Children in this stage have problems taking another's' viewpoint; e.g., when a child is looking at a picture in a book and draws his mother's attention to this picture, it does not realize that the mother is not able to see the picture when she is sitting opposite the child. From this, one can deduce that they will not be able to determine the utility of a negotiation to another party. In the concrete operational stage, the egocentrism fades away and children's limited social cognition is improved, enabling them to make judgments about utility to another by the end of the concrete operational stage. Once a certain level of development has been reached there will be no regression; therefore, once a cognitive aspect has been developed, it will not be lost. This explains why the Feeling for utility to other is also developed in the formal operational stage.

Table 2 summarizes the results of mapping the cognitive aspects to Piaget's stage theory. This table denotes that in the concrete operational stage, most of the cognitive aspects are developed. From these results, the target group age could be determined. According to Piaget [7], the developments are only complete at the end of each stage. He also showed, using the containment experiment [7], that children are not able to learn a certain task when they have not yet reached the required level of development. Keeping this in mind, the target group age was determined to be around 10 years of age. The mapping of the aspects to Piaget's theory was confirmed by a semi-experiment, in which three 10 year old children played a game of Settlers of Catan. This is also the lower age limit set by the makers of Settlers of Catan.

The findings presented in Table 2 are also confirmed by Gobet [5] who states: "Parker argues that children understand the concept of rules ... at about 6 years of age, even if they sometimes forget specific rules or change them during play. They also understand the concepts of winning and losing. But they only apply rules consistently ... at 11 or 12 years of age." (p.139) and "Sutton-Smith ... reports an association between level of games played by children and their presumed level of cognitive development based on their age." (p. 140).

Table 2: Cognitive Aspects developed in each stage of Piaget's theory, where ✗ and ✓ denote respectively that a cognitive aspect is or is not developed.

Aspects / Stage	Pre-operational	Concrete operational	Formal operational
Feeling for numbers	✗	✓	✓
Feeling for fairness	✗	✓	✓
Feeling for utility to self	✓	✓	✓
Feeling for utility to other	✗	✓	✓
Ability to keep goal in mind	✓	✓	✓
Ability to hypothesize	✗	✗	✓

3 Expert System

Founded on the theoretical framework discussed in the previous section, the expert system of the ITA was developed. This enabled the ITA to trace the level of development of children. The latter is achieved by determining what cognitive aspects are not fully developed and give advice accordingly.

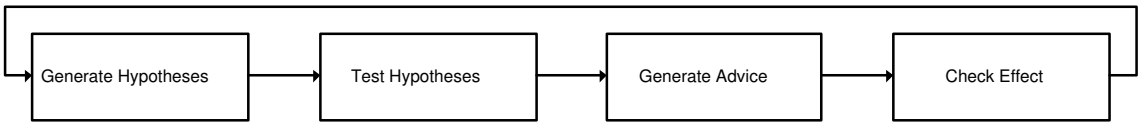

Figure 2: Global architecture of the expert system, adopted from [11]. The Generate Hypotheses module puts forth a hypothesis about whether or not a cognitive aspect is developed, this is then checked by the Test Hypotheses module. The Generate advice module supplies an advice message when the previous module has found an aspect undeveloped. The Check Effect module determines whether the same mistake is made again.

3.1 Architecture

For the architecture of the expert system, a number of expert system models were considered. Schreiber et al. [9] describe a number of knowledge model templates in their book on knowledge engineering. When considering these knowledge templates, three can be seen as candidates for the architecture of the expert system of the ITA: the assessment, diagnosis, and monitoring templates. The assessment template only takes one point in time into account. The monitoring template only registers a discrepancy and does not look at the cause of it. The diagnosis template, on the other hand, does incorporate both these characteristics and is, therefore, the most suitable of the three. The architecture of the expert system is based on this knowledge template.

The global architecture of the expert system is presented in Figure 2. Based on the negotiation history of the user, hypotheses are generated consisting of the cognitive abilities that have been defined (e.g., the hypothesis that the *Feeling for fairness* aspect has not yet been fully developed). Subsequently, the hypotheses will be tested; this will be done by checking whether or not all the facts necessary for this hypothesis are satisfied. Hence, the agent will check if there is more evidence that this hypothesis is true; if not, it will wait until there is or until the game ends. Once a hypothesis is validated, advice is generated based on this hypothesis. This advice is generated based on the number of times a certain error has been made, which is determined by the check effect component. The advice will become more explicit as more errors are made.

3.2 From framework to expert system

The rules in the modules of the expert system were designed from global to specific, with the cognitive aspects as starting point. The agent assumes that all the cognitive aspects have been developed and tries to disprove them. For the latter purpose, first the system determines whether or not a cognitive aspect needs to be elicited. Next, the system checks whether or not that aspect has been developed by asking a set of questions. Figure 3 provides some sample questions for the *Feeling for fairness* aspect.

Feeling for fairness:

- How often does the subject try to close an unfair (asking more than giving) deal?
  - 0 - 5 *
  - 5 - 10
  - $>$ 10
- How often does the subject accept an unfair deal?
  - 0 - 5 *
  - 5 - 10
  - $>$ 10

* Expected interval if cognitive ability has been fully developed.

Figure 3: Questions for cognitive aspect Feeling for fairness.

For each of the six cognitive aspects, questions were defined and, subsequently, converted into symbolic rules. An example of a symbolic rule used in the *Generate Hypothesis* and *Test Hypotheses* modules is provided in Figure 4. For a full list of questions and the symbolic rules deduced from these questions, see [4].

IF		Offer unfair deal
OR		Accept unfair deal
THEN		Hypothesis(NOT feeling for fairness)
IF		Hypothesis(NOT feeling for fairness)
AND		Offer unfair deal
AND		Accept unfair deal
THEN	NOT	Feeling for fairness

Figure 4: Example rule from the *Generate Hypotheses* (top) and *Test Hypotheses* (bottom) modules; see also Figure 2.

Each module of the expert system architecture contains its own knowledge base. These knowledge bases have been implemented in CLIPS [8]. The CLIPS knowledge bases and their inference engine are connected to the ITA, which is developed in JAVA, using JCLIPS [6], allowing JAVA to control the CLIPS inference engine. The ITA, which is connected to a digital version of SoC (JSettlers), determines whether or not the basic facts used in the knowledge bases are true. An example of a rule utilized by the ITA for determining two specific facts (*offer unfair deal* and *accept unfair deal*, used in Figure 4) is shown in Figure 5. The combination of Figures 3, 4, and 5 illustrates the phases in which the cognitive aspects from the theoretical framework are implemented into an expert system.

Given: Negotiation(fromPlayer, toPlayer, giveSet, getSet),

IF	fromPlayer == monitoredPlayer
AND	giveSet < getSet
THEN	Offer unfair deal
IF	toPlayer == monitoredPlayer
AND	giveSet < getSet
AND	offer accepted
THEN	Accept unfair deal

Figure 5: Example rules for specific facts: offer and accept an unfair deal. The given fact containing information about what is offered (giveSet) and what is asked (getSet) and which players are involved is obtained from the digital version of Settlers of Catan. Offering an unfair deal holds when the monitored player is offering and when he asks more resources than he is willing to offer. Accepting an unfair deal holds when the accepting player is the monitored player, when he is accepting less resources than he gives in return, and when the offer is actually accepted.

4 Intelligent Tutoring Agent

The ITA is a package that is integrated into the original JSettlers client (the SOCPlayerClient class, where SOC stands for Settlers of Catan) Consequently, the agent will be automatically started by the JSettlers client when a game is started. Moreover, the ITA is able to retrieve information about the game through the JSettlers client.

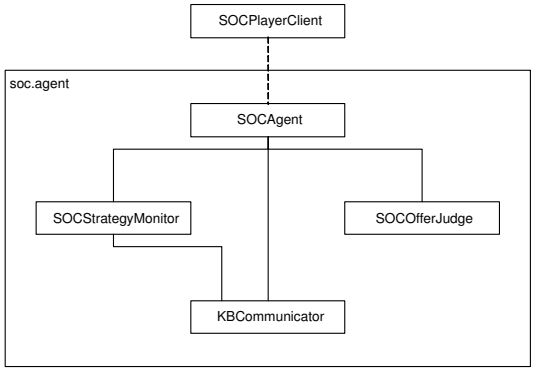

Figure 6: Architecture of the Intelligent Tutoring Agent: The agent is started by the SOCPlayerClient, and uses the Strategy Monitor and Offer Judge to handle some of the information processing. Both the SOCAgent class as the StrategyMonitor class utilize a knowledge base. The KBCommunicator class handles the communication with the knowledge bases.

4.1 Architecture

The agent uses a number of components for information processing. The three most important information processing components are: 1) the Strategy Monitor, 2) the Offer Judge, and 3) the KBCommunicator (Knowledge Base Communicator). Each of these components is used by the agent to handle part of the incoming game information. The Strategy Monitor handles information about strategies the player is or is not using, it utilizes a knowledge base to deduct crucial information. The Offer Judge handles all information about negotiations during the game. The KBCommunicator is responsible for the communication between the ITA and the expert system. Both the main class of the agent (SOCAgent) and the Strategy Monitor utilize knowledge bases and, thus, use the KBCommunicator. See Figure 6 for a schematic overview of the architecture of the ITA.

4.2 Interface

The interface is an added panel to the original JSettlers interface. This panel contains an area where the user can communicate his strategy to the agent. It contains a button that will open a new window that shows statistical information on the negotiation history. Moreover, tips to the user can be displayed, dependent on which strategy the player is using. Changes in the cognitive aspects detected by the agent and the corresponding text messages are provided to the user inside a dialog window. These windows will pop-up at the end of a turn. The agent will collect messages until the user ends his turn and they will be displayed then. A screenshot of the JSettlers interface with the added ITA component is provided in Figure 7.

4.3 Strategies

As mentioned in the previous section, the interface offers the user the possibility to communicate the strategy he is using to the agent. The agent is also able to determine what strategy the player is using by analyzing the behavior of the player during the game. A separate knowledge base has been developed to capture the knowledge needed with each strategy. When the agent has determined that the player is using a certain strategy, the user is informed and the strategy is marked in the user interface. Then, the agent can offer tips about negotiation possibilities. For instance, if a player is following the longest road strategy[1], he needs wood and stone to be able to buy roads. If the player has enough stone, but is lacking wood, the agent will suggest to the user he negotiates with fellow players to obtain the needed resource, wood in this case. An example of such a suggestion can be seen in the *Tips* section in Figure 7.

[1]The longest road strategy is focused on obtaining the longest trade route award. This award can be obtained by owning the longest set of uninterrupted roads, this award is worth two victory points.

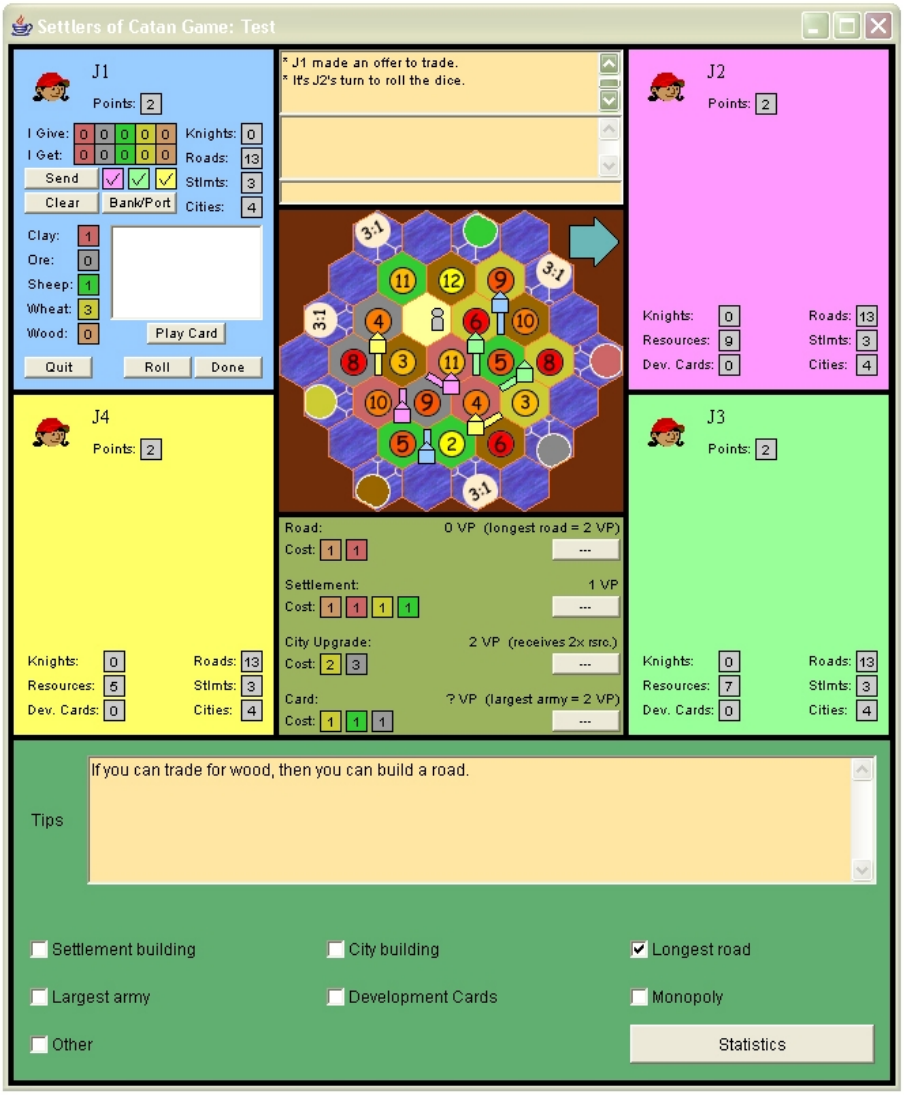

Figure 7: Screenshot of JSettlers with the ITA. At the bottom of the interface, the ITA interface can be seen. By pressing the statistics button, a window pops-up, containing statistical information on the negotiations. An aspect button in that window enables the pop up of a window that shows what cognitive aspects are still under investigation by the ITA.

5 Discussion

A new theoretical framework is presented based on the theories of Piaget [7] and of Thompson and Hastie [12], which defines six cognitive aspects needed for successful negotiation. Next, the newly developed Intelligent Teaching Agent (ITA) is presented, which utilizes an expert system for Settlers of Catan (SoC), based on the identified six cognitive aspects. This enables the ITA to compare the behavior of children to the knowledge of an expert negotiator. Subsequently, based on the latter comparison, advice can be provided to the child that plays SoC. Hence, through playing children can learn, supervised by the ITA, how to negotiate.

Currently, follow-up research is planned that aims to determine the learning effect of the current implementation of the ITA. To achieve the latter, experiments will be conducted in which subjects play SoC with and without the ITA. Consequently, both situations (i.e., with and without ITA) can be compared.

Follow-up research will aim at the improvement of the learning effect. Such an improvement can be realized in multiple ways. A more complex student model can be used; e.g., a qualitative model [2] or a neural network. Such a model would allow the ITA to make a more precise estimate of player's deficiencies, enabling it to offer even more tailored advice to the player. Alternatively, the method of providing the

messages to the player can be changed. Currently, this is done in a straight forward manner. When this is done in a more dynamic way (e.g., by using an animated agent), the learning effect could be improved [1].

In this paper, an Intelligent Tutoring Agent (ITA) is introduced for the complex, interactive board game Settlers of Catan. The agent utilizes a newly developed theoretical framework, which enables it to judge the level of understanding of negotiation in children and help them in developing it. A unique ITA is introduced, which helps children in developing negotiation skills through playing.

Acknowledgments

We thank Catholijn Jonker for her help during the start of the project and Maarten Menken for his help on JCLIPS. Robert Thomas is honored for his work on the JSettlers project. Further, we thank the students and children who participated voluntary in our experiments. Nanja Smets and Giovanni Piantoni for reviewing the manuscript.

References

[1] A.L. Baylor and Y. Kim. Pedagogical agent design: The impact of agent realism, gender, ethnicity, and instructional role. In *Intelligent Tutoring Systems,7th International Conference*, pages 592–603, 2004.

[2] B. Bredeweg and R. Winkels. Qualitative models in interactive environments: An introduction. *Interactive Learning Environments*, 5(1):1–18, 1998.

[3] J.S. Bruner, A. Jolly, and K. Sylva, editors. *Play: its role in development and evolution*. Harmondsworth, 1976.

[4] J. Geuze. An intelligent teaching agent for settlers of catan. Master's thesis at the Department of Artificial Intelligence, Vrije Universiteit Amsterdam, 2005.

[5] F. Gobet, A.J. de Voogt, and J. Retschitzki. *Moves in mind : The psychology of board games*. Psychology Press, 2004.

[6] M.R. Menken. JCLIPS – CLIPS for Java. `http://www.cs.vu.nl/~mrmenken/jclips/` [Last accessed on September 6, 2006].

[7] P.H. Miller. *Theories of Developmental Psychology*, chapter 1. Worth Publishers, 4th edition, 2002.

[8] Gary Riley. CLIPS: A tool for building expert systems. `http://www.ghg.net/clips/CLIPS.html` [Last accessed on September 6, 2006].

[9] G. Schreiber, H. Akkermans, A. Anjewierden, R. de Hoog, N. Shadbolt, W. van de Velde, and B. Wielinga. *Knowledge Engineering and Management, The CommonKADS Methodology*, chapter 6. MIT Press, 2000.

[10] T. Smith. *The Settlers of Catan*. Mayfair Games, 1996. `http://unicornsrest.org/reference/catan/mf_rules.htm` [Last accessed on September 6, 2005].

[11] Mark Stefik. *Introduction to knowledge systems*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1995.

[12] L. Thompson and R. Hastie. Judgement tasks and biases in negotiation. *Research on Negotiation in Organizations*, 2:31–54, 1990.