

# Interactive Cognitive Modelling Agents - Potential and Challenges

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**Abstract:** Interactive cognitive modelling agents are defined here as diagnostic agents that involve human learners in diagnostic dialogues and extract a picture of the learner's cognition in terms of beliefs, misunderstandings, misconceptions, and reasoning. This paper is written both as a reflection on our recent work on interactive open learner modelling, which is a specific and fairly simplified interactive cognitive modelling method, and as a proposal for developing a framework for interactive cognitive modelling agents. We discuss advantages of the approach and outline pitfalls with the initial architecture suggesting possible research techniques to tackle these problems.

**Key words:** interactive cognitive modelling, meta-cognition, evaluation.

## 1 Introduction

Learners expect to be understood when they ask for advice, assistance, explanation, guidance, tutoring, etc. Effective adaptive learning environments require robust learner models (LMs) (Self, 1999) that represent learners' preferences, needs, knowledge, misconceptions, skills. Diagnosis is a mutual process – it depends on the diagnosee's involvement and the diagnoser's ability to encourage this involvement (Dillenbourg, 1996). Learners would expect the computer teachers with whom they are interacting to be willing to participate in a discussion about their problems rather than providing quick, incomplete, and incomprehensible responses. The result of such diagnostic interactions is eliciting a picture of the learner's cognition with the active participation both of the learner and the teacher. Not only is interactive diagnosis likely to be more accurate and to enable effective personalisation, but when it does take place in educational situations, it can bring deeper insights for both the teacher in terms of reflection on their own practice and the learner in terms of promoting important meta-cognitive skills. Such wealth diagnostic interactions are increasingly needed nowadays in many advanced learning environments – particularly systems that require sophisticated learner models and promote meta-cognition to help learners understand themselves what their problems and needs are.

In contrast, traditional computer diagnostic systems seek to infer the reasons for the learners' behaviour without directly involving the learners. Recently, approaches that involve learners in diagnosis have been proposed (Bull et al., 1995; Bull & Brna 1999; Kay, 1995; McCalla et al., 2000; Morales et al., 2000; Paiva & Self, 1995; Zapata-Rivera & Greer, 2001). Most of these methods are concerned with *open learner modelling* where the learners are provided with the means to inspect and change the models the systems build of them. Commonly, these systems externalise the LMs in some viewers and provide menu options for the learners to change the content of their models. The users can sometimes ask for explanations and justifications of the computer's opinions. The approach proposed by Bull (1997) suggests an enhanced method of interaction in a menu-based environment for *negotiating* the learner model. When inconsistencies between the student and the computer's views about the student's beliefs are identified, negotiative dialogue is triggered. However, naturally occurring human-human diagnostic interactions, e.g. peer diagnostic systems (Bull & Brna, 1999), accommodate a richer set of communicative activities – the dialogue comprises multiple exchanges, no one controls or restricts what another may say (at the same time some participants, e.g. the teacher, might be attributed a guidance role), and all parties can change the topic and initiate a new discussion. Such rich interactions that aim at extracting a model of the learner's cognition are addressed in this paper.

This position paper will discuss the design of a new diagnostic architecture - artificial agents that understand human users by talking and listening to them. More specifically, we will present Interactive Cognitive Modelling Agents (ICOMAs) - *computer diagnosers capable of involving learners in an ongoing dialogue that results in eliciting models of the learners' cognition with the active participation of the learners*. We will present an initial exploration of the approach - interactive open learner modelling, illustrated in the system STyLE-OLM.

Advantages and possible applications of ICOMAs will then be discussed. Finally, we will sketch out further research towards extending STyLE-OLM to provide a framework for interactive cognitive modelling. We will outline challenges and will speculate about possible solutions in order to accommodate more advanced domain reasoning, richer communication means, extended dialogue management, and enhanced learner model maintenance.

## 2 Interactive Cognitive Modelling Agents

Human teachers follow a variety of diagnostic tactics when they guide diagnostic dialogue. To illustrate, let us consider an excerpt from the communication between a teacher and a language student who studies for technical translator and faces problems with some domain terms. Similar dialogues have been observed in early studies we have conducted with university students in Bulgaria (Dimitrova & Dicheva, 1998). Note, that the actual dialogue was in Bulgarian, the translation below is done by the author. The domain concepts mentioned in the dialogue are given in small capital letters.

[1] Learner. I have heard people talking about PASCAL but I know nothing about it. Is PASCAL related to WINDOWS?

[2] Teacher. We will need to discuss some other terms before I can answer your question. Have you heard of OPERATING SYSTEMS?

[3] Learner. Yes, I think so. Isn't this MsDos?

[4] Teacher. MsDos is one example of an OPERATING SYSTEM. Do you know any other OPERATING SYSTEMS?

[5] Learner. No. I thought OPERATING SYSTEM meant MsDos and am confused now. What is an OPERATING SYSTEM?

[6] Teacher. OPERATING SYSTEMS are COMPUTER PROGRAMS that maintain the communication between a COMPUTER and the PROGRAMS that run on it. MsDos is one example of an OPERATING SYSTEM. WINDOWS is another example of an OPERATING SYSTEM.

[7] Learner. You mean WINDOWS is the same as MsDos?

[8] Teacher. Not exactly the same. Different OPERATING SYSTEMS provide different means for people to contact with the OPERATING SYSTEM and to control the COMPUTERS. While in MsDos people have to write COMMANDS in order to communicate with the OPERATING SYSTEM, WINDOWS provides a GRAPHICAL USER INTERFACE which uses menus and icons.

[9] Teacher. Let's return back to your question. To compare WINDOWS and PASCAL, we need to talk also about PROGRAMMING LANGUAGES.

[10] Learner. You mean languages used to write programs? My friends did some BASIC at school.

[11] Teacher. That is right. BASIC is an example of a PROGRAMMING LANGUAGE. So is PASCAL. PROGRAMMING LANGUAGE allow programmers to write PROGRAMS, which are run on a COMPUTER with the help of an OPERATING SYSTEM, for example WINDOWS.

This example shows that diagnostic dialogues are naturally embedded into the whole teaching process. We propose that these dialogues are conducted by *Interactive Cognitive Modelling Agents* which aim at extracting a picture of the learner's cognition. Such agents will have to share resources with other parts of an interactive learning environment, for example, domain expertise and learner model. These agents may serve as main diagnostic components in learning environments. They could also be used together with other diagnostic methods (e.g. assessing learners' drill performance) to enhance the quality of the learner models by addressing aspects that may well have been missed or diagnosed wrongly by the traditional diagnostic methods. To build models of ICOMAs, we will make the following assumptions:

- ICOMAs share common communication means with the learners where domain facts are discussed and models of the learners' conceptual understanding are extracted. The communication language should allow effective diagnostic interactions where both a diagnosee and a diagnoser participate actively.
- The interaction comprises a sequence of episodes which span over multiple turns and follow specific diagnostic tactics. ICOMAs plan the content of the interaction and take diagnostic decisions based on their domain expertise. These agents are empowered by discourse knowledge that enables them to lead a coherent interaction aimed at eliciting a picture of the diagnosee's conceptual understanding

- ICOMAs' aim is to elicit a picture of the learner's conceptual understanding in terms of beliefs (as in the example above), misunderstandings, misconceptions, and reasoning. These agents must incorporate appropriate reasoning capabilities that enable the extraction of an interactively constructed learner model.

Computational frameworks of interactive cognitive modelling agents will allow understanding the process and will provide vehicles for building *robust computer simulations of interactive teachers* capable of understanding the learners' problems and needs. Moreover, formalisations will aid the implementation of diagnostic agents in various domains.

### 3 Initial Exploration – STyLE-OLM

We have examined a specific interactive cognitive modelling method, called *interactive open learner modelling* (IOLM), where a learner is provided with the means to inspect and discuss the conceptual models that computer systems build of them (Dimitrova, 2001). Despite the fact that IOLM agents focus mainly on discussing the content of the learner model and demonstrate a fairly simplified case of the interaction discussed above, it has confirmed the feasibility of the assumptions discussed in section 2. Many techniques from this specific method appear fruitful in the more advanced diagnostic model the ICOMAs address.

A formal framework for interactive open learner modelling has been developed (Dimitrova et al., 1999; Dimitrova et al., 2000; Dimitrova 2001). It includes distinctive components: a *discourse model* based on an approach known as dialogue games manages diagnostic interactions and provides both a diagnoser and a diagnosee with a common communication method and symmetrical power in dialogue maintenance (Dimitrova et al. 1999, Dimitrova et al., 2002) while a formally defined mechanism based on a belief modal operator adopts nonmonotonic reasoning to maintain a jointly constructed LM (Dimitrova et al., 2000). The framework has been demonstrated in STyLE-OLM - an IOLM system in a terminological domain (Dimitrova, 2002). Two instantiations of STyLE-OLM – in Computer Science and in Finance - have been developed, the example here is from an experimental study with the system conducted in a Finance domain (topic – Financial Markets). The study involved seven post graduate students from the author's department. More details about the study are given in Dimitrova (2001).

The excerpt below shows a fragment of an interaction with STyLE-OLM where the system challenges the robustness of a learner's conceptualisation, which provides for reflection and scaffolding of the learner's domain knowledge. Initially, the learner model contains information that the learner knows some aspects of the terms MONEY MARKET and CAPITAL MARKET but often mixes these terms. STyLE-OLM initiates a dialogue to explore the learner's knowledge about these terms and to find possible reasons for the confusion.

- [1] STyLE-OLM<sub>[inquire]</sub> DO YOU THINK MONEY MARKET operates with SHORT TERM INVESTMENTS.  
 [2] Learner<sub>[agree]</sub> I AGREE that MONEY MARKET operates with SHORT TERM INVESTMENTS.  
 [3] STyLE-OLM<sub>[inquire]</sub> CAPITAL MARKET raises CAPITAL and operates with WHAT?  
 [4] Learner<sub>[inform]</sub> I THINK that CAPITAL MARKET operates with SHORT TERM INVESTMENTS.

The dialogue follows a game tactic that elaborates on the similarities and differences between the two terms. Move [4], however, reveals an erroneous aspect of a learner's knowledge: the proposition 'CAPITAL MARKET operates with SHORT TERM INVESTMENTS', which the learner is assumed to believe, is not confirmed by the diagnoser's domain knowledge. A new dialogue episode is initiated searching for some explanation for the learner's error.

- [5] STyLE-OLM<sub>[challenge]</sub> WHY DO YOU THINK CAPITAL MARKET operates with SHORT TERM INVESTMENTS?  
 [6] Learner<sub>[justify]</sub> BECAUSE CAPITAL MARKET operates with TREASURY BILLS and TREASURY BILLS are SHORT TERM INVESTMENTS.

The screen shot in Figure 1 depicts the environment at the moment when the learner constructs his justification. The system now registers a possible reason for misattribution: the student may believe wrongly that 'CAPITAL MARKET operates with SHORT TERM INVESTMENTS' because he believes that 'CAPITAL MARKET operates with TREASURY BILLS and TREASURY BILLS are SHORT TERM INVESTMENTS'. Since the last belief has also not been confirmed by its domain expertise, STyLE-OLM initiates a new dialogue episode for explaining this error:

- [7] STyLE-OLM<sub>[challenge]</sub> WHY DO YOU THINK CAPITAL MARKET operates with TREASURY BILLS and TREASURY BILLS are SHORT TERM INVESTMENTS?

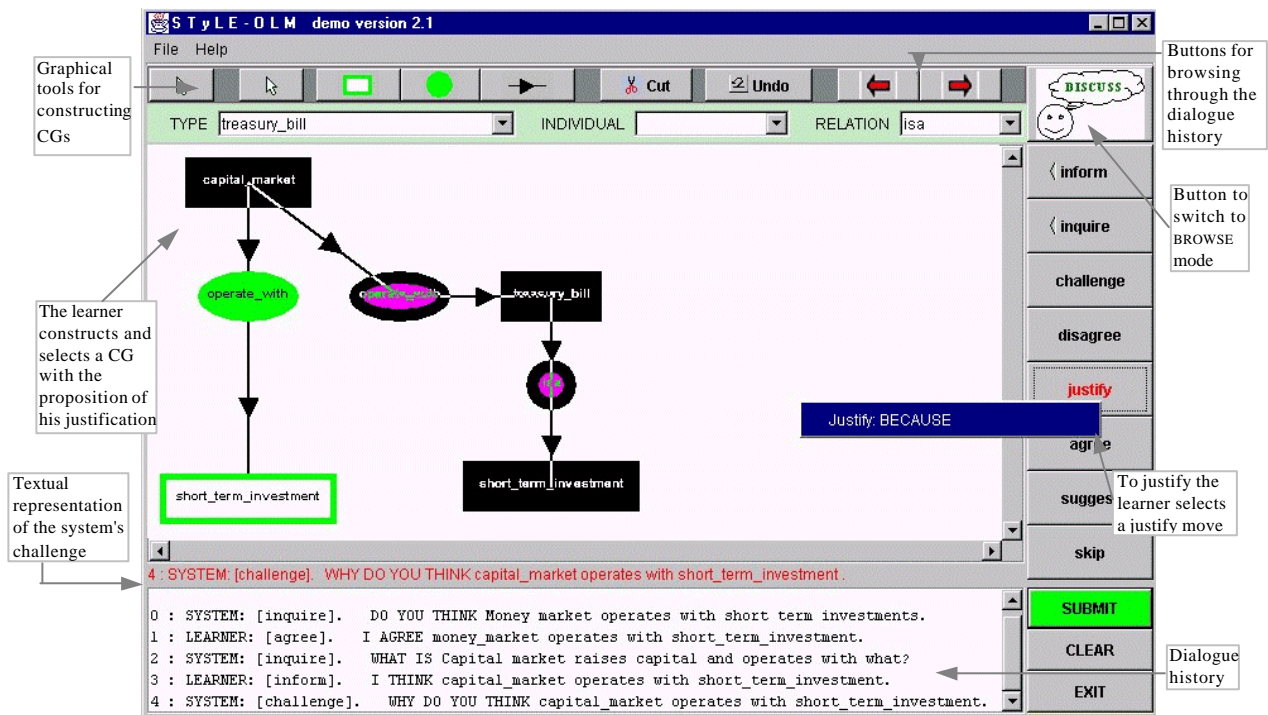


Figure 1. Learner's justification in STyLE-OLM (move [6]).

At this time, the student is confused. The robustness of his domain beliefs is challenged. He switches to a BROWSE mode where he browses through the beliefs in the LM and sees the level of correctness the system assigns to them. Having seen that the belief presented in Figure 2 has been classified as *known wrongly* by the system, the learner realises that his claim that CAPITAL MARKET operates with TREASURY BILLS and TREASURY BILLS are SHORT TERM INVESTMENTS might be wrong.

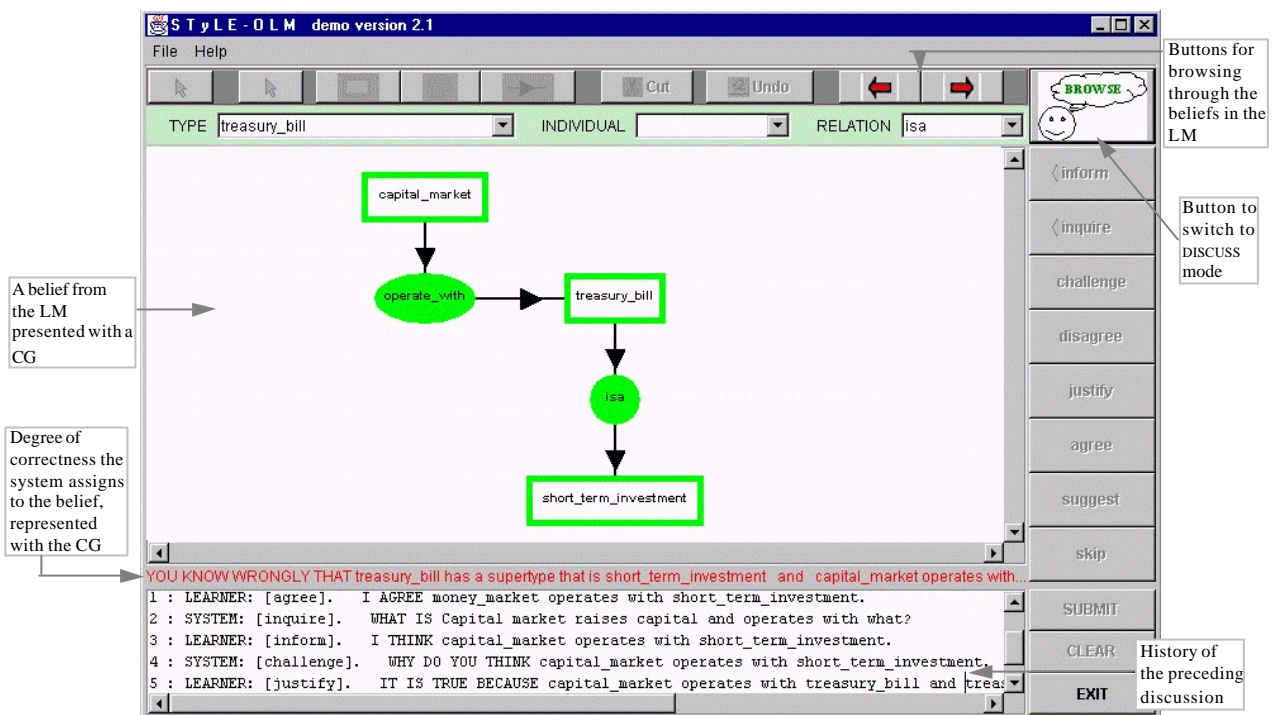


Figure 2. The STyLE-OLM environment in BROWSE – the learner browses the beliefs in the LM provoked by the system's challenges in move [7].

He now needs the system's help to explore facts about these terms. He switches back to DISCUSS mode to continue the discussion of the LM. He asks a question:

[8] Learner<sub>[inquire]</sub> IS IT TRUE that TREASURY BILLS are SHORT TERM INVESTMENTS?

[9] STyLE-OLM<sub>[inform]</sub> I KNOW that TREASURY BILLS are SHORT TERM INVESTMENTS.

The learner realises that one part of his statement in [6] is correct and challenges the other:

[10] Learner<sub>[inquire]</sub> IS IT TRUE that CAPITAL MARKET operates with SHORT TERM INVESTMENTS?

[11] STyLE-OLM<sub>[inform]</sub> I DO NOT KNOW that CAPITAL MARKET operates with SHORT TERM INVESTMENTS.

The learner has clarified the part of his beliefs which is wrong. He withdraws his claim that CAPITAL MARKET operates with SHORT TERM INVESTMENTS.

[12] Learner<sub>[disagree]</sub> I DISAGREE that CAPITAL MARKET operates with SHORT TERM INVESTMENTS?

The interaction continues with the comparison between MONEY MARKET and CAPITAL MARKET. Due to space restrictions, we will not present the whole dialogue here. A full transcript of this dialogue as well as some other example interactions with STyLE-OLM are given in Dimitrova (2001). After the dialogue is terminated, a jointly constructed learner model that takes into account what has been expressed by the two agents during the interaction is obtained (e.g. the belief 'CAPITAL MARKET operates with SHORT TERM INVESTMENTS' will be deleted from the initial LM).

STyLE-OLM allows inspecting and discussing the learner model in a relatively expressive graphical manner which fosters the articulation of domain knowledge and can lead to conceptual understanding. A constructive dialogue guided by the system enables the exploration of aspects of a learner's domain knowledge and the extension of the scope of beliefs in the learner model. Learners are provided with a symmetrical role in maintaining the dialogue. A flexible diagnostic mechanism allows the management of a learner model jointly constructed by the computer system and the learner with the latter being provided with equal power to influence the diagnosis.

### 3.1 Potential of Interactive Cognitive Modelling Agents

Interactive cognitive modelling agents have a strong potential in advanced learning environments capable of tailoring to the needs of the learners and promoting meta-cognitive processes. The evaluative study with STyLE-OLM has demonstrated advantages of the approach in terms of improving the quality of the learner model and providing the means for reflective activities (Dimitrova et al., 2001, Dimitrova, 2002).

- *Improving the quality of the learner model.* We observed fewer inconsistencies in the resulting LM, a larger scope of learner's beliefs, and some explanations of the learner's errors. The obtained LM included a higher proportion of valid assertions about the learner's knowledge and minimised the number of not valid assertions about the learner's knowledge.
- *Providing means for reflective activities.* The study allowed us to monitor the following reflective activities with STyLE-OLM: the students rendered statements about their domain beliefs, they went back to claims about their beliefs and (sometimes) changed these claims, and they investigated arguments to support their beliefs. While more knowledgeable learners were engaged in reflective dialogues about the domain, less knowledgeable learners were provoked to inspect their models and challenge the robustness of these models.

ICOMAs can be embedded in advanced e-learning systems to enable better understanding of the learners and to help learners understand themselves what their accomplishments and problems are. There is a growing interest in finding robust and computationally tractable methods for eliciting models of the users' cognitive states to aid the development of personalised systems in various domains, especially in the increasingly popular Internet applications. ICOMAs can be used as a basis for developing sophisticated personalised Internet agents, for example personal e-consultants or e-metntors.

- *Personal e-consultants* are interactive agents that offer personalised advice tailored to the users' problems and needs. Such agents may be incorporated in modern e-commerce or e-banking systems. For example, a non expert in financial planning seeking to understand the concept of an "ISA" may be provided with a personal e-consultant that discusses the domain terminology with the user, infers a model of the user's conceptual understanding, and offers adaptive explanations tailored to the user's understanding of the terminology.

- *E-mentors* are agents that act as personal mentors. Mentoring is a relationship in which one person - usually someone more experienced - helps another to discover more about themselves, their potential and their capability. The mentor's role is to listen, ask questions, probe for facts and understand its mentee and to act as a source of information, experience, and advice. Artificial mentors could be embedded in new generation e-training systems to provide the means to understand the trainees, offer personalised help, and help the trainees identify themselves what their needs are.

While the evaluation of STyLE-OLM outlined potentials of the IOLM framework, it also revealed unsolved aspects that led to pitfalls of the architecture. We will sketch out these aspects next and will draw speculations about how they may be addressed in a more sophisticated framework for ICOMAs.

## 4 Challenges

In this section, based on examining learner interactions with STyLE-OLM, we outline further improvements of the IOLM framework in order to maintain enhanced diagnostic interactions required in interactive cognitive modelling.

### 4.1 Exploring advanced domain inference

Interactive cognitive modelling requires high level logic in order to develop appropriate tactics to reveal reasons for users' misconceptions. We have experimented with conceptual graphs, which have been found a suitable formalisation for the purposes of interactive diagnosis. However, some commonsense reasoners, such as *modus tollens*, which are often applied by humans have been difficult to capture. This led sometimes to missing student reasoners and interrupting profitable dialogue episodes. In order to address negations of domain propositions represented with conceptual graphs, an additional modal operator *not* shall be considered (Sowa, 1984), a methodology how this can be implemented in computer applications is discussed in Dau (2000).

ICOMAs need to analyse propositions composed by the users. It is difficult to predict how the learners will express their propositions. Even in a highly structured graphical communication language exploited in STyLE-OLM (Dimitrova et al., 2002), computational problems with *ambiguity* of domain propositions became apparent. Firstly, many relations have overlapping of their meanings in everyday language. When learner mixed such relations (e.g. "agent" and "actor", see (Sowa, 1984)) STyLE-OLM assigned erroneous conceptualisation while the learners had simply confused very similar words. Dealing with mixed relations requires some representation of interdependencies between relations and suitable reasoning to find relation similarities. For example,  $\lambda$ -definitions of relations used in conceptual graphs theory (Sowa, 1984) may empower such reasoning.

Secondly, often a proposition is a re-phrase of another, which, if not captured by the domain reasoning mechanism, may lead to misdiagnosis or obscure dialogue moves such as repetition or inappropriate challenging. Extended comparison techniques to allow for different perspectives of the same knowledge to be captured are needed. Mechanisms, similar to those presented in (Dieng & Hug, 1998; Martin, 2000) seem applicable in ICOMAs.

Dealing with ambiguity of domain propositions requires not only discovering potential ambiguous situations but also addressing them in the dialogue. Meta-dialogue for dealing with mis-communications and grounding, e.g. (Traum & Dillenbourg, 1996), need to be incorporated in the dialogue maintenance mechanism.

The study with STyLE-OLM showed the need to handle reasoning under *incomplete domain expertise*. When the system did not have information about a domain fact, it simply assumed that this was an erroneous belief and challenged it, which led to inappropriate system behaviour at times (e.g. a learner's statement "A bank operates with money" was not confirmed by the system's domain expertise and challenged "Why do you think a bank operates with money", which frustrated the learner). A less knowledge-centred behaviour of the diagnostic agent is required. We may envisage that at times the diagnostic agent behaves as a *peer* who may extend its competence to incorporate information provided by the learner depending on its *trust in the learner* and *its own domain reasoning*. Planning diagnostic dialogue when the diagnoser's domain expertise is incomplete seems to relate to decision making under uncertainty which deals with reasoning that require information not available at the time it is needed. One way to tackle the problem is to employ some form of *defeasible reasoning*, i.e. to make some assumptions from which some conclusions may be drawn and withdraw the assumptions later on if

the assumption is proven invalid (Davis, 1990; Parsons, 2001). In this case, ICOMAs will need to have a mechanism for dealing with the *degree of certainty* about the truth of domain propositions. Another possible method to deal with incomplete domain expertise is *argumentation* (Krause & Clark, 1993; Parsons, 2001). For instance, an ICOMA may accept a proposition suggested by a student if it cannot find a rebuttal for it. In this case, the agent needs to be able to incorporate some kind of argumentative reasoning in its dialogue planning.

#### **4.2 Providing rich communication means**

STyLE-OLM provided a graphical communication medium combining propositions represented as conceptual graphs and illocutions represented with sentence openers. While, such environment was found favourable for diagnostic interactions (Dimitrova et al., 2002), some problems were also identified.

Firstly, mixing textual and graphical representations requires keeping the meaning of both representations coherent. When graphics is utilised for constructing dialogue utterances, a sophisticated mechanism for generating linguistic expressions from graphics is needed in order to provide linguistically coherent text that represents the meaning of the graphical expressions. When communication is based on conceptual graphs, natural language processing approaches that generate text from graphs, e.g. (Angelova & Bontcheva, 1996; Nikolov et al., 1995), may be employed.

Secondly, there is no comprehensive study of the type of operations needed when communication is done with graphics, for example how to facilitate the construction of graphical utterances, the modification of graphical "propositions", the search through graphical expressions, etc. We adopted a rather heuristic approach following conventional operations used in graphical packages but it became apparent that a more systematic approach is needed to examine the effectiveness and pitfalls of these operations. In this line, approaches from Human-Computer Interaction seem favourable, for example (Green & Petre, 1996).

Thirdly, the participants in the evaluation of STyLE-OLM did not agree regarding their choice of graphics or text for communication. The study was too limited to discuss this issue deeply, and further exploration is needed. In this line, (Cox, 1999) provides possible directions highlighting the difference between situations in which a presented external representation is interpreted and situations in which participants construct external representation (both types of situations are present in communicating with diagrams). As Bull et al. (2001) argue, differences in the learners' cognitive styles impose a variety of communication means to be combined in a single system. Since the associations between cognitive style and presentation format are not straightforward, Bull et al. propose that learners' should be given the choice of a textual or graphical environment (in domains for which either may be appropriate) for discussing their cognitive model. Providing text input would require student diagnosis based on a free text, which is a challenging computational task at present, e.g. the learners' statements may not make sense according to the system's domain model. Recent research in natural language processing is addressing relevant aspects (e.g. Ramsay & Seville, 2000) and one would expect in due course interactive cognitive modelling to accommodate communication in a free natural language. This would open a new research issue of how to accommodate misunderstanding, repair and grounding (e.g. Traum & Dillenbourg, 1996) in a dialogue which is aimed at student diagnosis.

#### **4.3 Maintaining a coherent diagnostic dialogue**

Maintaining a coherent diagnostic dialogue requires dealing with *vague* and *incomplete* information about possible learner's misconceptions and suitable diagnostic tactics. Reasons for people's cognitive errors are generally difficult to define. There is a fair bit of work done on defining theories for concept learning that deal with the correct application of rules such as generalisation, specification, similarity (Thagard, 1982). However, very little has been done to precisely define types of rules that people apply wrongly or fail to apply, which leads to building wrong or incomplete conceptual models. In this line, in order to deal with vagueness of defining diagnostic tactics, ICOMs would need to appropriately incorporate methods for reasoning under uncertainty (Krause & Clark, 1993; Parsons, 2001).

An important role of ICOMAs is to scaffold learners' conceptual understanding. This can be achieved via adopting a variety of strategies to discuss wrong beliefs, e.g. comparison (Milosavlevic, 1997), explanation (Bontcheva & Wilks, 1999; McCoy, 1989), inquiry dialogue (Wong et al., 1998). In addition, learners need to be navigated through the dialogue in order to help them understand the semantic structure of the conversation. At times, the learners in the study with STyLE-OLM felt that the system was jumping between different

propositions without any obvious reason for this, and the learners failed to follow what was going on. Diagnostic dialogue can be improved if the diagnoser makes apparent the rhetorical structure of the conversation, for instance what the current dialogue tactic is, why the system is changing the tactic, when the system goes back to a previously initiated dialogue episode, etc. To illustrate this, we present below an improvement of the dialogue example given above with added phrases to explain the rhetorical structure of the conversation.

- [1] STyLE-OLM<sub>[inquire]</sub> It seems that you confuse the terms MONEY MARKET and CAPITAL MARKET. We can try to compare these two terms here. DO YOU THINK MONEY MARKET operates with SHORT TERM INVESTMENTS.
- [2] Learner<sub>[agree]</sub> I AGREE that MONEY MARKET operates with SHORT TERM INVESTMENTS.
- [3] STyLE-OLM<sub>[inquire]</sub> We just mentioned the definition of MONEY MARKET. We are trying to compare MONEY MARKET and CAPITAL MARKET, so let us consider the definition of CAPITAL MARKET. CAPITAL MARKET raises CAPITAL and operates with WHAT?
- [4] Learner<sub>[inform]</sub> I THINK that CAPITAL MARKET operates with SHORT TERM INVESTMENTS.
- [5] STyLE-OLM<sub>[challenge]</sub> I see, you think that both MONEY MARKET and CAPITAL MARKET operate with SHORT TERM INVESTMENTS. Can you explain what makes you think that CAPITAL MARKET operates with SHORT TERM INVESTMENTS?
- [6] Learner<sub>[justify]</sub> IT IS TRUE BECAUSE CAPITAL MARKET operates with TREASURY BILLS and TREASURY BILLS are SHORT TERM INVESTMENTS.
- [7] STyLE-OLM<sub>[challenge]</sub> This is a fact that I didn't know you believed. Can I ask you to confirm that you believe CAPITAL MARKET operates with TREASURY BILLS and TREASURY BILLS are SHORT TERM INVESTMENTS?
- [8] Learner<sub>[inquire]</sub> IS IT TRUE that TREASURY BILLS are SHORT TERM INVESTMENTS?
- [9] STyLE-OLM<sub>[inform]</sub> Well, to my knowledge, TREASURY BILLS are SHORT TERM INVESTMENTS.
- [10] Learner<sub>[inquire]</sub> IS IT TRUE that CAPITAL MARKET operates with TREASURY BILLS?
- [11] STyLE-OLM<sub>[inform]</sub> To the best of my knowledge, I can't confirm that CAPITAL MARKET operates with TREASURY BILLS.

Sessions with STyLE-OLM have revealed that both the diagnoser and the diagnosee may need to express uncertainty in their dialogue utterances. For example, the diagnoser may deal with information that is not available and may need to make assumptions about the student's knowledge, while the student may not be completely sure about the validity of their statements. Consequently, diagnostic dialogue has to accommodate different verbal expressions of uncertainty, such as definite, likely, possible, unlikely, and impossible (Krause & Clark, 1993).

#### 4.4 Eliciting a learner model under uncertain conditions

The result of a method for student modelling is a model of the student's cognition. Following the discussion above, it is apparent that the mechanism for eliciting a resultant student model has to accommodate reasoning under uncertainty. While some level of uncertainty might be handled via interaction enabling agents to challenge or withdraw their beliefs and to clarify their statements, a more elaborated notion of uncertainty would be sensible. For example, representing some strength of beliefs in the learner model (e.g. 'entirely sure', 'not very sure', 'guessing') and making plausible inferences that incorporate degree of belief and nonmonotonic reasoning (Parsons, 2001).

The study with STyLE-OLM confirmed that *inconsistency* is often a case in students' beliefs. Although clarification dialogue in STyLE-OLM did enable us to handle inconsistency in student beliefs and avoid extensive belief revision (Giangrandi & Tasso, 1995), we found that some contradicting propositions were left due to limitations of the system's reasoning (e.g. a learner was thought to believe both 'CAPITAL MARKET operates with LONG TERM INVESTMENTS' (correct) and 'CAPITAL MARKET operates with TREASURY BILLS' (wrong), which are actually contradictory because TREASURY BILLS are not LONG TERM INVESTMENTS but SHORT TERM INVESTMENTS). Therefore, a reasoning mechanism that explores deeper all consequences of the student's claims is required. A feasible approach seems advanced nonmonotonic reasoning (Davis, 1990).

The mechanism for ascribing participants' beliefs from their communicative acts would have to adjust the belief ascription according to the agents' goals. In STyLE-OLM, when asking questions learners were diagnosed that

they did not know a domain fact. However, a question may not always indicate missing knowledge, but may sometimes mean that the students seek for confirmations of domain aspects they know. Further extensions need to take into account theories that deal with the repair of mistaken ascriptions, e.g. (Lee & Wilks, 1997).

## 5 Conclusions

This paper is written both as a reflection on our recent work on interactive open learner modelling and as a proposal for further research on interactive cognitive modelling. Our long term goal is to develop *robust and efficient models* of computer agents that can conduct diagnostic dialogues with a learner (or a group of learners) in order to understand the learners and help themselves understand what their problems and needs are. One type of such diagnostic agents - Interactive Cognitive Modelling Agents - have been discussed in this paper. ICOMAs are interactive diagnostic agents that involve human learners in diagnostic dialogues and extracts a picture of the learner's cognition in terms of beliefs, misunderstandings, misconceptions, and reasoning. As an initial exploration of the approach we have examined a method called interactive open learner modelling where a computer diagnoser enables a human learner to inspect and discuss the model the diagnoser builds of him/her. STyLE-OLM - the system we have built to illustrate our IOLM framework - is a rather simplified demonstration of ICOMA. However, it did allow us to observe some advantages of the approach, which were outlined in the paper. We have also sketched out potential problems with STyLE-OLM and have pointed to possible methods to tackle these problems in an enhanced architecture of interactive cognitive modelling agents.

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