The Interactive Maintenance of Open Learner Models

Vania Dimitrova, John Self and Paul Brna
Computer Based Learning Unit, University of Leeds, Leeds LS2 9JT, UK
E-mail: { V.Dimitrova, J.A.Self, P.Brna}@cbl.leeds.ac.uk

Abstract. Opening the learner model is a process involving the learner as a collaborator in building a model of his beliefs. The interaction plays a crucial role here since it provides both the system and the learner with a medium to reflect on the learner's beliefs. In this paper we describe a computational framework for the interactive maintenance of open learner models. It adopts some approaches from human-human interaction and considers the two main issues of the interaction – the language for communication and the underlying dialogue model. We describe a communication language that graphically externalises the learner's beliefs. An approach based on dialogue games is adapted to manage the moves in an interactive diagnostic dialogue. The framework is exemplified in STyLE-OLM, an open learner modelling component in a scientific terminology learning environment.

1 Introduction

In traditional student diagnosis, the system seeks to infer the reasons for the learner's behaviour without direct help from the learner. A potentially more accurate alternative is to involve the learner in the process of building the learner model (LM) with both the learner and the system sharing in the activity of inspecting and changing the LM.

The interaction plays a crucial role in open learner modelling environments since it provides both the system and the learner with a medium to reflect on the learner's beliefs. Moreover, through the interaction, information about the LM can be provided by the learner to the system assisting the system in learner modelling. Therefore, how to maintain system-learner interaction is a crucial issue in open learner modelling systems. TAGUS [11] and UM [8] use *viewers* that present the LM on the screen and supply command options so that the learner can submit his changes. The learner's suggestions are accepted or not by the system according to its priority mechanism. Mr Collins [3] negotiates with the learner when there is a disagreement in the confidence measures of the student's beliefs given by the two sides. The interaction occurs only if there is a conflict in the belief measures. Examples of interactions in peer diagnosing systems, however, show a diversity of dialogue moves that occur when two people discuss their belief models (c.f. [4]). People are motivated to reflect on their LM and to discuss it with human peers ([4], [7]). With a computer system, the learners show lower motivation, e.g. more than half of the students using UM have browsed their LMs mainly passively without any significant interest [8]. If we compare human-computer and human-human interactive diagnosis, it is plain that the communicative abilities of the computer systems and those given to the learner are severely limited. The dialogue is very restricted - it usually comprises a single exchange in which the learner must respond to a system's question. Then, the learner's response is strictly delimited by the system's choices and often he cannot ask for another option. Adopting models from human-human interaction is a favourable approach to design interactive open learner modelling environments that can lead to improved reflection and motivation.

In this paper, we describe a computational framework for the interactive maintenance of open learner models. Unlike the systems discussed above, we have adapted models from human-human communication to maintain the interaction between the system and the learner when discussing the learner model. The main issues of our approach are exemplified in STyLE-OLM, an open learner modelling component in a scientific terminology learning environment. The learner model and the role of interaction in STyLE-OLM are described in §2 and §3, respectively. We present a conceptual graph (CG) [15] interactive environment that provides a diagrammatic communication language and a graphical externalisation of the learner's beliefs (see §4.1). An approach based on dialogue games (DGs) is adapted to specify the dialogue moves that both participants can use to discuss the learner model (see §4.2). A dialogue example is given in §4.3.

2 The Learner Model in STyLE-OLM

A learner model represents the system's beliefs about the learner's beliefs accumulated during the diagnostic process.The LM represents those aspects of the learner's knowledge that are regarded as significant for determining the actions of the intelligent learning environment (ILE). STyLE-OLM is intended for use as an open learner modelling component in a scientific terminology ILE. In STYLE-OLM, the system and the learner discuss the learner's conceptual knowledge. The jointly constructed LM can be used as a source for adaptive feedback and content planning in a terminological ILE.

It has been shown that conceptual graphs can be used in a terminological ILE to represent the subject area knowledge [6]. STyLE-OLM uses the same formalism to represent the *learner's beliefs* about concepts and their relations. We consider two *belief stores* representing what the system thinks about the learner's domain expertise. The first store consists of CGs that show what the *system believes that the learner believes* (S_bL_b). S_bL_b includes *correct* or *erroneous* learner's beliefs. Comparing the learner's behaviour with its domain expertise, the system may conclude that the learner has not created certain relations presented in its domain model. These refer to the learner's *incomplete* knowledge, namely what the *system believes that the learner does not believe* ($S_bL_{\neg b}$). Figure 1 shows part of the LM in a Computer Science domain (CGs are presented in linear form [15]).

S_bL_b:	*G1_c*:	[OBJECT] --
		→ (*contain*) → [DATA]
		→ (*contain*) → [OPERATION: {*}]
	G2_e:	[OBJECT-ORIENTED PROGRAM] → (*false friend*) → [OBJECT PROGRAM]
	C1_e:	[OBJECT-ORIENTED LANGUAGE: VISUAL BASIC]
	C2_c:	[OBJECT-ORIENTED LANGUAGE: C++]
$S_bL_{\neg b}$:	*G3_ic*:	[ACTION: TRANSLATE] --
		→ (*instrument*) → [OBJECT LANGUAGE]
		→ (*object*) → [OBJECT PROGRAM]
		→ (*agent*) → [COMPILER]
		→ (*object*) → [SOURCE PROGRAM]
	G4_ic	[OBJECT-ORIENTED LANGUAGE] --
		→ (*contain*) → [OBJECT: {*}]
		→ (*contain*) → [CLASS: {*}]
		→ (*characteristic*) → [ENCAPSULATION]
		→ (*characteristic*) → [INHERITANCE]
	C3_ic:	[OBJECT-ORIENTED PROGRAM]
	C4_ic:	[OBJECT PROGRAM]

Figure 1. Part of the LM in STyLE-OLM: belief stores are represented as CG sets.

When the learner's beliefs differ from the system's domain expertise the student's problems need some kind of *explanation* for the ILE to decide what to do. Thus, in addition to the learner's beliefs, the LM includes learner's *misunderstandings* that explain his erroneous and incomplete knowledge. We consider three groups of misunderstandings: (1) language similarities that cause conceptual problems (e.g. OBJECT-ORIENTED PROGRAM and OBJECT PROGRAM can be confused because they contain the term OBJECT); (2) communication and representational problems (the first concerns misunderstanding dialogue moves and the second concerns problems with the communication environment); and (3) *misconceptions* are those misunderstandings that are hard to correct and are at heart conceptually wrong. They are crucial for the learner's conceptual modelling. Misconceptions in STyLE-OLM are derived from concept learning theories [17] and formalised with rules based on CGs. Three main classes of errors are considered:

- *misclassification* - an individual *I* is wrongly considered as a member of a class *C*;
- *class misattribution* - an attribute *A* is wrongly attached to a class *C*;
- *individual misattribution* - an attribute *A* is wrongly attached to an individual *I*.

To illustrate, table 1 shows two misconception rules to explain *misclassification errors*.

Table 1. Misclassification rules in STyLE-OLM in a Prolog notation: find_gr/2 searches the LM for graphs containing a class or an individual; find_indiv/2 searches for an individual from a given class; generalisation/3 finds the generalisation [15] of two graphs. The examples depict reasons for a student to believe wrongly that VISUAL BASIC is an OBJECT-ORIENTED LANGUAGE.

misclassification_1(I,C,A) :- find_gr(I,G1), find_gr(C,G2),generalisation(G1,G2,A). The individual has features that are part of the class features, e.g.VISUAL BASIC [I] is an OBJECT-ORIENTED LANGUAGE [C] because it "contains OBJECTS" [A].
misclassification_2(I,C,J,A) :- find_indiv(C,J), find_gr(I,G1), find_gr(J,G2), generalisation(G1,G2,A). The individual has common features with an individual that belongs to the class, e.g. VISUAL BASIC [I] is an OBJECT-ORIENTED LANGUAGE [C] because both it and VISUAL C++ [J] allow "programming in a VISUAL ENVIRONMENT" [A].

3 The Role of STyLE-OLM in Learner Modelling Process

Learner modelling combines both observation and interaction. We assume that the ILE calling STyLE-OLM has an observational component that builds a preliminary LM (such as the one shown in figure 1). STyLE-OLM is an *interactive diagnosis tool* where the *rough* LM is refined through a discussion with the learner. The ILE *opens* a discussion about the LM, i.e. it enters STyLE-OLM, when there are problems with the observational diagnosis:

- The learner makes the same errors several times although the system always gives him proper feedback. The ILE needs either to refine the information about this error in the LM or to find a sophisticated explanation, i.e. the misconception behind it.
- The learner shows a belief that is *very wrong*. For example, he thinks that OBJECT PROGRAM and OBJECT-ORIENTED PROGRAM are interchangeable but according to the system's knowledge they are not conceptually related. In this case, the ILE may go to an interaction about the LM in order to add, refine and delete learner's beliefs.
- The system does not have enough information to decide what the student knows about a term and faces problems about what the next action should be. To decide how to react when the learner uses the term erroneously, the system has to fill the gap in the LM, i.e. to add more information about the learner's beliefs.

The student himself has the most to gain from a successful diagnosis. He might be supposed to be motivated for full engagement in the diagnostic process. For example, he may discover that the system is not very adaptive when it gives him explanations for terms that he knows very well and misses others he feels not very aware of. Then the learner can enter STyLE-OLM and initiate a discussion about the LM.

To summarise, we consider both the learner and the ILE entering the interactive diagnosis component. The main actions on the learner model in this component are: (1) *add* new beliefs; (2) *refine* existing beliefs; (3) *delete* beliefs; and (4) *explain* beliefs (find out the misunderstandings that cause erroneous or incomplete beliefs).

4 The Interaction Model in STyLE-OLM

Any interaction involves a set of conventions for communicating (a *communicative language*) and a model that monitors the components of the communication (a *dialogue model*). Next in this section we discuss these issues presenting the interaction model in STyLE-OLM which is based on the following assumptions:

- The system and the learner are provided with a *common language* that allows them to express and understand their actions.
- In the utterance of a "sentence" in this language, the speaker is able to indicate both the *propositional content* and the *illocutionary force* [14] in a way that allows the hearer to understand them clearly.
- The system-learner interaction is *rule governed*. This decreases the ambiguity of utterances and reduces the computational complexity of the dialogue model.

4.1 Communication language

Researchers from different areas have formalised human-machine interaction as a *set of communicative acts* (CAs) and *rules* for monitoring these acts in order to achieve communicative goals. For example, Baker [1] defines the main negotiative CA and presents a model of negotiation in teaching-learning dialogues. Maybury [10] describes a plan-based communicative act approach for generating multimedia explanations.

In STyLE-OLM the *communicative acts* are the minimal units of interaction. We consider a communication language based on a graphical representation of conceptual graphs that allows the system and the learner to create propositions when discussing the content of the LM. Some advantages of such an approach are: (1) *Natural mapping*. The graphical representation externalises student's beliefs represented with CGs (see §2) and provides a direct mapping between the external and internal system representation. We can hypothesise that being a kind of semantic network, CGs externalise the learner's internal mental representation which is built as a network connecting concepts with corresponding relations [5]; (2) *Expressiveness*. CGs have been used for translating computer-oriented formalisms to and from natural languages. CGs also inherit the high logical expressiveness of semantic networks [16]; (3) *Cognitive effect*. Communication based on diagrams can operate as a medium for thinking and understanding [2].

Our graphical communication approach is based also on the results of a study carried out to investigate whether people can read, build, manipulate, and communicate with CGs. The subjects, 29 secondary school Bulgarian students (17-18 yrs), studied in a specialised mathematical school where technical subjects (Computer Science in particular) were taught in English. Only three students had a little experience with graphs, nobody knew CGs. The study had three phases: *training* (introduction of the main CGs notations); *test* (6 questions to check the use of CGs for communication); *discussion* (post-experiment commentaries and suggestions from the participants). The study showed that the students understood information presented with CGs and, to a certain degree, expressed their knowledge by using CGs. The subjects extracted the relationships between concepts and understood questions expressed with CGs. They created answers easily by changing CGs to represent the necessary meanings by adding new concepts/relations. The study showed some negative aspects in communicating with CGs, mainly concerning the ambiguity of relations and the directions of the arrows. Students also failed to build a new conceptual graph when they were given an English sentence. Most of them described this as a difficulty in distinguishing the main concepts and the relations that held between them in the text. Some students made useful comments such as "CGs helped me to distinguish clearly the concepts and the relationships between them" or "CGs keep language ambiguity and I am still confused with the meaning." The study showed that CGs could be used as part of the communication medium in a terminological learning environment. Some of the problems it indicated were taken into account in the design of the CGs communication language.

STyLE-OLM provides a multimodal communication environment combining graphics, text, and some interface widgets such as menus and buttons. Following Maybury's taxonomy [10] we distinguish between *graphical* and *linguistic acts* in a multimodal communication. The former concern manipulating in a graphical medium (pointing, adding, moving, deleting, etc.) and the latter are the main dialogue moves and relate to speech acts in linguistic communication [14].

The dialogue moves in STyLE-OLM are adapted from Pilkington's DISCOUNT scheme[1] for analysing educational dialogues [12]. Preliminary selected dialogue moves were refined with a Wizard of Oz study where the designer played the role of STyLE-OLM and interacted with a colleague who played the role of a learner (an example of this interaction is given in $4.3). The dialogue moves in STyLE-OLM are: *Inform* (the speaker believes a proposition and informs the hearer about that); *Inquire* (the speaker asks about a proposition); *Challenge* (the speaker doubts a proposition); *Withdraw* (the speaker disagrees with a proposition); *Justify* (the speaker explains why a proposition is correct); *Agree* (the speaker agrees with a proposition); *Suggest* (the speaker suggests a new focus of the discussion); *Deny* (the speaker denies the suggested focus shift).

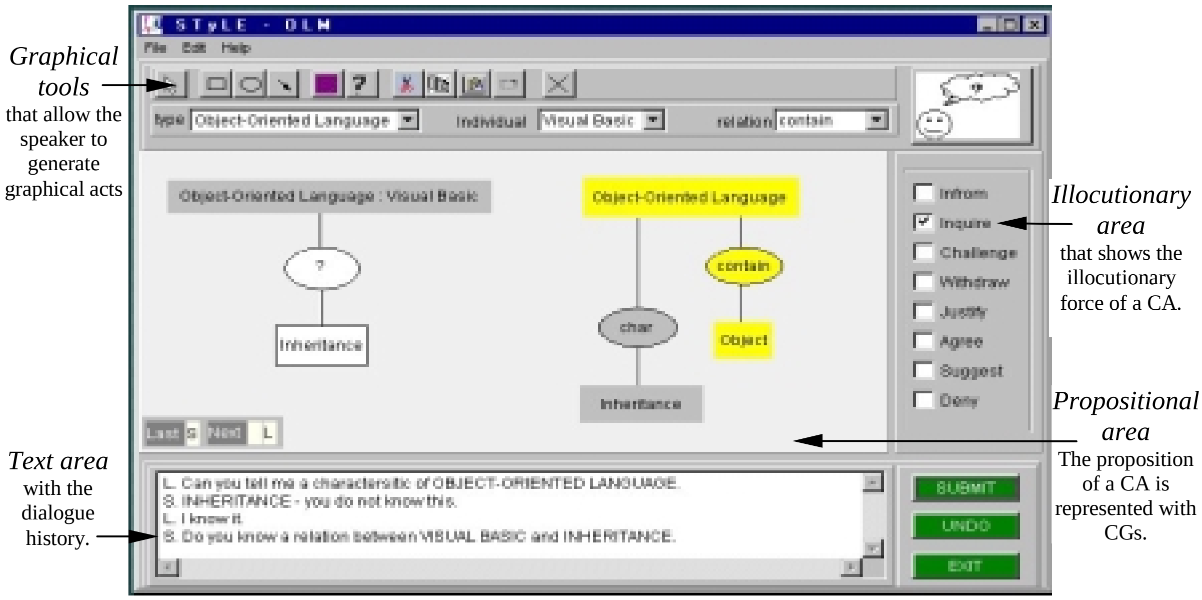

Figure 2. Dialogue move 9 from the example in §4.3 in the STyLE-OLM environment. The system (1) "points" to the terms OBJECT-ORIENTED LANGUAGE and INHERITANCE (graphical act - blinking); (2) creates a new ellipse for a relation and puts a question mark inside; (3) selects "Inquire" from the illocutionary area; (4) "submits" its move by "pressing" the button SUBMIT (blinking); (5) finally, the text explaining the dialogue move appears in the text area below. Follows a learner's turn.

[1] DISCOUNT considers many dialogue moves. We have taken those we intuitively thought related to a diagnosing dialogue.

In the performance of a speech act, Searle [14] distinguishes "the proposition indicating element and the function indicating device". When analysing the utterances one can separate the analysis of these two. In human-human conversations, the boundaries of the propositional and illocutionary parts are often interdependent. In our *artificial* communication environment they are shown explicitly. By combining different *graphical acts* the speaker can express the propositional content of a CA. This is done in a diagrammatic *propositional* area (see figure 2) where CGs represent current propositions. The illocutionary force is explicitly indicated by selecting a dialogue move (see the illocutionary area in figure 2). This resembles the use of *performative verbs* to indicate the illocutionary force of a speech act [14]. For example, selecting the *Inform* verb and drawing a graph *G* means "Inform that P_G" where P_G is the proposition presented with the graph G.

4.2 Dialogue model

The dialogue structure in STyLE-OLM is based on *dialogue games*. DG theory is a formal device for generating well-formed sequences of dialogue moves and is based on studies of naturally occurring human dialogues [9]. Following the main structure of a DG and the extensions described in [13] needed for a computer system to participate in an argumentative dialogue, we have designed the communication model in STyLE-OLM. The main DG components are adapted for interactive diagnosis and are described below.

- *Dialogue moves* are described in §4.1.
- *Commitment stores* (relate to the belief sets discussed in §2) represent each participant's beliefs about the learner's subject area knowledge.
- *Commitment rules* define the effects of moves upon the players' commitment stores (see table 2).
- *Game rules* define when the moves are allowed (i.e. which are the preceding moves of a move) and thus describe the pragmatic structure of the dialogue (see table 2).

Table 2. DG commitment rules and game rules. *P* and *Q* indicate propositions represented with CGs. Propositions indicated with the same letters in different rows are not connected.

Preceding moves	**Dialogue move**	**Commitment Store Rules**	
		Speaker	**Hearer**
{*Inform*(Q), *Inquire*(Q), *Challenge*(Q), *Withdraw*(Q), *Justify*(Q), *Agree*(Q), *Suggest*(Q), *Deny*(Q)}	***Inform*(*P*)**	add *P*	add *P*
{*Inform*(Q),*Inquire*(Q), *Suggest*(Q),*Deny*(Q)}	***Inquire*(*P*)**	add *not P*	
{*Inform*(P)}	***Challenge*(*P*)**	delete *P*	
{*Inform*(P)}	***Withdraw*(*P*)**	delete *P*; add *not P*	
{*Challenge*(Q), *Withdraw*(Q)}	***Justify*(*P*)**	add (*P*->Q)	
{*Inform*(P),*Justify*(P)}	***Agree*(*P*)**	add *P*	
{*Inform*(Q),*Inquire*(Q), *Justify*(Q), *Agree*(Q), *Suggest*(Q),*Deny*(Q)}	***Suggest*(*P*)**		
{*Suggest*(P)}	***Deny*(*P*)**		

In order to take part in a dialogue the system needs a *strategy* that defines the meta-level of the dialogue [13]. The strategy rules in STyLE-OLM fulfil diagnostic goals. So far we have considered three sets of strategy rules that allow the system to *play* three kinds of DGs. *Explain Learner Errors* aims at finding the misconceptions causing the learner's errors. STyLE-OLM will follow a *Collect More Information* strategy when the LM does not contain enough beliefs for a particular term. The main aim of this game is to add more beliefs and it follows the principle to discover as much information as possible concerning the last concept discussed. When a conflict arises between the system and the learner's beliefs about the learner's knowledge, then a *Resolve Conflicts* game starts. DG rules allow most of the conflicts to be solved during the interaction in the previous two games. However, after withdrawing the other side's statement instead of accepting it and changing the beliefs in their commitment stores, the speaker may initiate a negotiative game. Examples of strategy rules for the *Explain Learner Errors* game that the system plays in the dialogue in 4.3 are:

ER1 Ask the learner to confirm all the conditions before assigning a misconception.

ER2 IF there is a misconception which has only one missing condition
THEN inquire about this condition
OR make a statement with this condition.

ER3 IF there is a condition connected with the term under discussion and this condition can lead to an explanation of a misconception
THEN inquire about this condition
OR make a statement with this condition.

ER4 IF there is more than one possibility to an explain an error
THEN consider those conditions that have been discussed most recently.

ER5 IF the suggested focus graph has a concept that appears in a condition of a misconception
THEN accept the focus shift
AND inquire about this condition or make a statement with it.

4.3 An Example dialogue

With the model discussed above the system is able to participate in a dialogue about student's beliefs. The example below is from the Wizard of Oz study described in $4.1. STyLE-OLM plays an *Explain Learner Errors* DG trying to find out why the student wrongly thinks that VISUAL BASIC is an OBJECT-ORIENTED LANGUAGE. For the sake of space we present the dialogue in a text form. In this dialogue, the learner suggests a discussion topic (move 2), states a proposition to start an exchange (move 4), and requests more information (move 6).

1. $S_{[Inform,\ ER1]}$ You think that VISUAL BASIC is an OBJECT-ORIENTED LANGUAGE.
2. $L_{[Suggest]}$ Let us talk about OBJECT-ORIENTED LANGUAGE.
3. $L_{[Inform]}$ I know that an OBJECT-ORIENTED LANGUAGE contains OBJECTS.
4. $S_{[Inquire,\ ER3]}$ Can you tell me a characteristic of OBJECT-ORIENTED LANGUAGE.
5. $L_{[Inform]}$ OBJECT.
6. $L_{[Inquire]}$ Can you tell me a characteristic of OBJECT-ORIENTED LANGUAGE.
7. $S_{[Inform,\ ER5]}$ INHERITANCE - you do not know that.
8. $L_{[Withdraw]}$ I know it.
9. $S_{[Inquire,\ ER5]}$ Do you know a relation between VISUAL BASIC and INHERITANCE.
10. $L_{[Inform]}$ I do not know.
11. $L_{[Inform]}$ I know that VISUAL BASIC contains OBJECTS.

Since all the conditions for misclassification_1(VISUAL BASIC, OBJECT-ORIENTED LANGUAGE, "contains OBJECTS") are TRUE it will be inferred from the learner model.

5 Conclusion

Opening the learner model is a process involving the learner as a collaborator in building a model of his beliefs. Apart from building a more accurate learner model this approach has many positive effects promoting learner’s reflection and knowledge awareness [3]. These effects can be exacerbated rather than improved if we ignore the communication issue of diagnosis and build systems where the responsibility for interaction has been given mainly to the computer. We have presented a computational architecture to maintain the interaction in open learner modelling. Two main issues - communicative language and dialogue model - have been discussed. The framework is based on communication theories, an empirical study, and some intuitive decisions. It is exemplified in STyLE OLM - an open learner modelling component in a scientific terminology learning environment.

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