

The Design and Implementation of a Graphical Communication Medium for Interactive Open Learner Modelling

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Abstract. Our work explores an interactive open learner modelling (IOLM) approach where a learner is provided with the means to inspect and discuss the learner model. This paper presents the design and implementation of a communication medium for IOLM. We justify an approach of inspecting and discussing the learner model in a graphical manner using conceptual graphs. Based on an empirical study we draw design recommendations, taken into account in the implementation of the communication medium in STyLE-OLM - an IOLM system in a terminological domain. The potential and improvements of the medium are discussed on the basis of study with STyLE-OLM.

1 Introduction

A crucial issue in building intelligent tutoring systems capable of adapting to the needs of individual learners is maintaining computational models that represent the learners' preferences, needs and cognitive capacity [15]. Recently novel architectures that involve learners in diagnosis have been explored [2, 11, 13, 14, 19]. In line with these methods, we have investigated an approach, called interactive open learner modelling (IOLM), where learners are provided with the means to inspect and discuss the content of the models the systems build of them. Differently from the other overt diagnostic approaches, IOLM conceives diagnosis as an *ongoing dialogue* involving both a computer system and a learner that play symmetrical (to a certain extent) roles and construct together the learner model (LM). We argue that an IOLM system should involve the learner in a constructive interaction to reveal aspects of the learner's cognitive state. It should also provide suitable means for the learner to monitor the elicited LM, which may trigger new discussions that further alter the LM.

Our main goal has been to formalise the IOLM process in order to support the development of computer diagnosers that have the potential to elicit a more adequate picture of the student's knowledge and promote reflective thought [9]. Four aspects are vital in the design of an IOLM system [6]: defining suitable algorithms to extract the necessary domain knowledge for dialogue planning and diagnosis; managing diagnostic dialogue [7]; maintaining a jointly constructed LM [8]; and providing a communication medium for externalising and discussing the LM.

The purpose of this paper is to justify and present a graphical approach for designing and implementing a communication medium for IOLM. The role of such a medium is twofold: on the one hand it provides a means for rendering aspects of a

learner's cognition, on the other hand, it enables both the learner and the computer to express their dialogue utterances.

The design of a communication medium for IOLM depends on the structure of the domain to be learned and the aspects of the LM which are open for inspection and negotiation. We have developed a framework for IOLM where domain knowledge algorithms are exemplified with Conceptual Graphs (CG) [17] and the LM is built as an extended overlay upon the domain knowledge [6]. Part of the LM that contains the learner's domain beliefs, which are represented with CGs, is externalised and discussed with the learner¹. Accordingly, we have exploited a communication medium for IOLM that utilises graphically rendered CGs.

Next in the paper we will justify the use of a graphical communication medium for IOLM (section 2) and will present the design (section 3) and the implementation (section 4) of the medium used in STyLE-OLM - a demonstrator of IOLM in a terminological domain. The potential and improvements of the medium will be discussed on the basis of an evaluative study of STyLE-OLM (section 5).

2 Graphical Communication Medium for IOLM

The term medium is used here in accord with multimedia human-computer interactions as the physical 'carrier' to express and communicate information [3].

2.1 Externalising the Learner Model

A medium where a LM is open for a learner's inspection should meet certain criteria.

Understandability. Learners should be provided with a representation of the LM that they can easily understand. Studies reported in [14] and [19] suggest that learners tend to understand graphically rendered LMs. Well constructed diagrams aid processibility as they provide spatial clarity [12] and limited abstraction [18].

Effective Inspection. An effective representation must provoke inferential processes that may in turn provide for meta-cognition. Being less abstract than text, diagrams help people to confront their problem comprehension [4]. It is also expected that constructing external representations may promote self-explanation [4].

Reducing the Cognitive Load. LM inspection is in its nature a demanding cognitive task and LM representations that reduce the cognitive load are favourable. Well-constructed diagrams mirror the structure of what they represent and alleviate the inferential load [16]. Graphical representations that are capable of representing the information in a problem are processed quickly by the human visual system [4].

2.2 Discussing the Learner Model

The task of discussing a learner's beliefs imposes additional requirements to the design of a communication medium for IOLM.

¹ We also include the LM reasoning rules that may lead to erroneous and incomplete beliefs [6].

Expressiveness. Both the system and the learner should be able to express their dialogue utterances when discussing the LM. Natural language is highly expressive and provides rich communicative means. It has been pointed out that the expressive capacity of semantic networks is comparable to linguistic modalities [18]. Moreover, if a particular graphical system has similar logical power as a sentential system, the graphical representation may be preferable because of its clarity [18].

Effective Communication. The communication medium has to enable participants to understand expressions constructed by the other party. Natural language may hinder diagnosis due to the complexity of determining learners' conceptual errors from vague, ambiguous, and ungrammatical learner utterances. Less abstract diagrammatic languages [18] might overcome this problem when appropriate dialogue control assistance is provided, for example the propositional content may be rendered with diagrams and the illocutions expressed with sentence openers [1].

Symmetry. Similarly to collaborative student modelling [2], IOLM is a collaborative process where the student and the system jointly maintain the content of the LM and have a common aim to create a more accurate LM. Symmetry is a vital feature in collaborative interactions [5], which implies that a common interaction language that provides both participants with equal expressive power in constructing their dialogue utterances and allows sharing dialogue maintenance roles is needed.

To sum up, flexibly structured communications that combine graphically rendered domain content with sentence openers that express illocutionary force are fruitful for LM inspection and discussion. Semantic networks, a diagrammatic representation with formally defined syntax and semantics and high logical expressiveness, can be used for the domain content. CGs are semantic networks with constraints on their nodes and links, which aids tractability. However, to the best of our knowledge, there is no empirical evidence that people can understand and construct propositions expressed with CGs. We, therefore, conducted a small study to investigate these aspects and inform the design of a communication medium for IOLM based on CGs.

3 The Design of a Graphical Communication Medium for IOLM

The communication medium in IOLM systems implements the interface with the learner. Initial evaluation of interface features at a design-specification stage before investing time and resources for implementation is feasible [10].

We conducted a small study aimed to reveal potential problems of communication based on CGs by examining whether people can *read*, *construct*, *manipulate*, and *communicate* with CGs. A conceptual graph is a kind of semantic network which comprises two types of nodes - concepts (represented with rectangles) and conceptual relations (represented with ellipses) - connected by directed arcs [17]. Figure 1 shows a CG constructed by a participant in the study to represent a given sentence.

Participants. The participants were twenty four secondary school students (sixteen-eighteen years old) with no prior knowledge of semantic networks and CGs. The experiment was conducted anonymously during a Computing lesson in a school environment. The participants were an appropriate target group for the terminological domain we had chosen to demonstrate our IOLM framework (see section 4).

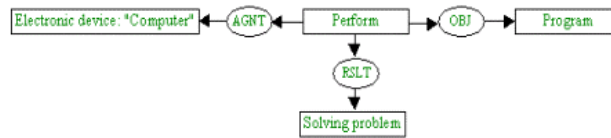


Figure 1. A CG drawn by a learner to represent the sentence ‘A computer is an electronic device which performs a number of instructions (program) on a set of data in order to solve a particular problem’. AGNT(agent), OBJ(object), RSLT(result).

Procedure and materials. Prior to the experiment, all participants were presented with a brief outline of its objectives in regard to a possible design of a computer-based communication medium. The study had three phases:

- *Training*, about half an hour, where an experimenter introduced the learners to the main CG notations. Each participant was given an *introductory text* with containing a CG overview and a *help text* with basic conceptual relations extracted from [17]. The students used both texts during the whole study.
- *Test*, half an hour, where the participants worked individually using pen-and-paper on a set of questions related to the objectives of the study as follows: *reading* - identifying relations presented in a CG and extracting propositions rendered with CG; *building* - understanding the lexical and syntactic structure of the representation, extracting a semantic structure of a sentence and formalising it in terms of concepts and conceptual relations organised in CGs; *manipulating* - deriving semantic notations from structural changes as well as modifying the structure to present new semantic relations; *communicating* - understanding and constructing questions with CGs.
- Post-experiment *discussion*, approximately 10 minutes, where participants provided some commentaries and suggestions.

The materials included Computing facts familiar to the participants. All CGs were presented in a graphical form and textual sentences were provided when appropriate.

Results and Design Recommendations. The participants’ answers to the test questions were classified in four groups - complete correct answer, incomplete correct answer (generally such answers were correct but did not cover all expected aspects), no answer, wrong answer, see Table 1.

Table 1. Summary of the students’ responses to the four tasks examined in the study.

	Complete correct answers	Incomplete correct answers	No answer is given	Wrong answers
Reading CGs	54%	23%	15%	8%
Building CGs	13%	25%	33%	29%
Manipulating CGs	50%	10%	19%	21%
Communicating with CGs	79%	8%	13%	0%

The results of the study confirmed a design choice to use CGs in a medium for IOLM. The students understood information presented with CGs and, to a certain degree, expressed their knowledge by using CGs. Relationships between concepts

were easily extracted and questions rendered with CGs were understood. CGs were relatively easily changed to represent the necessary meanings by adding new concepts/relations. Some students commented that the graphical representation helped them distinguish the domain concepts and relationships between them.

Whilst students could relatively easily understand CGs, they found it slightly more difficult to manipulate them correctly and found it quite difficult to construct new graphs. We outline below observed difficulties and draw design recommendations.

Problem. Learners may confuse conceptual relations. Some basic relations, e.g. ATTR (attribute) and CHAR (characteristic), are hardly distinguishable.

Recommendations. Using abbreviated relation names should be avoided. Patterns of often confusing relations may be collected (see section 5) and used in hints when a learner is believed to have mixed similar relations. The least possible number of basic, i.e. low level, relations [17] is recommended. High level relations which encode domain specific connections (e.g., in a Computing domain such a relation may be DEVELOPED) are less likely to cause ambiguity and should be preferred.

Problem. People tend to confuse link directions in CGs.

Recommendations. A textual equivalent supplied for each constructed graph may help learners identify wrongly directed arrows. Users should be provided with suitable means to correct their CGs.

Problem. Students may fail to build a new CG (from scratch) to express a textual sentence, while modifying existing graphs appears a relatively easy task.

Recommendations. In general, a graph modification should chiefly be encouraged in order to reduce the difficulty of constructing a conceptual graph. Ways to help the users build CGs should be provided, for instance, allowing the learners to inspect previously drawn graphs as well as allowing them to select and manipulate any of these graphs in order to utilise their graph constructions.

Problem. For some participants in our study it was difficult to distinguish the main concepts and the relations between them in the textual representation.

Recommendations. In order to avoid possible problems with constructing or altering conceptual graphs due to users' incapacity to elicit domain concepts and relations, a computer system may provide the learner with a clear indication of the CG 'vocabulary', e.g. all concepts and conceptual relations used in the particular application may be listed in an appropriate way.

The design recommendations have been taken into account in implementing the graphical communication medium in STyLE-OLM, outlined next.

4 The Communication Medium in STyLE-OLM

We will illustrate the implementation of a graphical communication medium for IOLM based on STyLE-OLM. STyLE-OLM is the Open Learner Modelling component in STyLE (Scientific Terminology Learning Environment) developed in the EU funded Larflast² project. STyLE-OLM is an environment for IOLM where learners can inspect and discuss aspects of their conceptual knowledge and influence

² The project involved partners from Bulgaria, UK, France, Romania, and Ukraine. See <http://www-it.fmi.uni-sofia.bg/larflast/> for more details.

the content of the LM. STyLE-OLM is described in detail elsewhere [6, 9], the focus here is on the interface of the system presented with examples in a Finance domain.

STyLE-OLM provides a multimodal communication environment that combines graphics (graphically rendered CGs), text, and some interface widgets such as menus and buttons. In this environment, learners can inspect and discuss their knowledge about domain terms. There are two modes:

- **DISCUSS** where learners can discuss aspects of their domain knowledge and influence the content of the learner model (Figure 2);
- **BROWSE** where learners can inspect the current state of their LM (Figure 3).

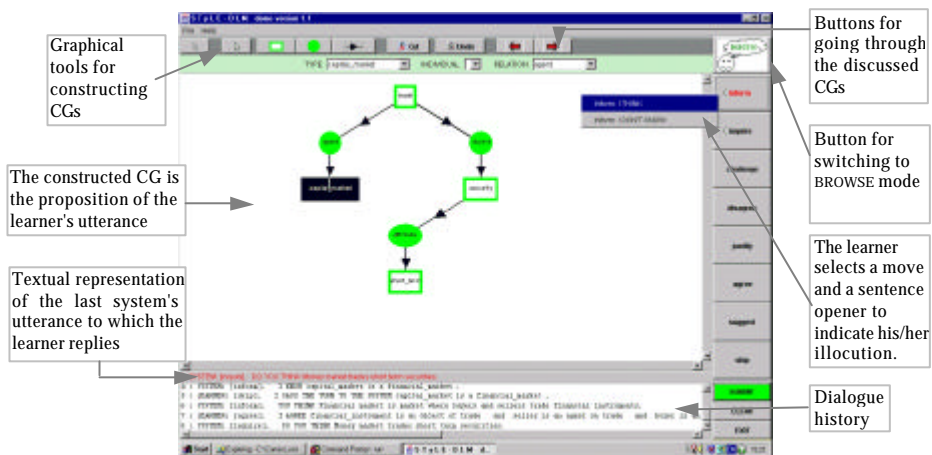


Figure 2. STyLE-OLM in DISCUSS mode. A learner's reply to a system's question.

A picture at the top right of the window presents the current system mode. The learner switches between the modes by pressing the button with this picture.

In DISCUSS mode, users compose their dialogue utterances by defining a *propositional content* (represented with a CG) and an *illocutionary force* (represented in a dialogue move). Graphical tools (at the top) facilitate CG manipulation and construction. The learner is provided with suitable means to *add*, *delete* and *change* graphical objects. The dialogue moves are indicated with sentence openers.

The learners submit their utterances by pressing the *Submit* button at the bottom right of the screen. The system then generates a textual form of the utterance and asks the learners for confirmation. The learners can either return to the graphical window to make some changes or confirm their utterance in which case a system turn follows.

Both the student and the system contribute to the discussion in the same way - by selecting or creating a graph component and a dialogue move. The system's proposition appears in the drawing area as a conceptual graph and the illocutionary force is shown in the bottom of the drawing window, see Figure 2.

A text window at the bottom shows a generated transcript of the dialogue. The learner can go through the dialogue history either in its textual form or by using the arrows in the graphical tools at the top. He/she can alter any of the previously discussed graphs to construct the proposition of their utterance.

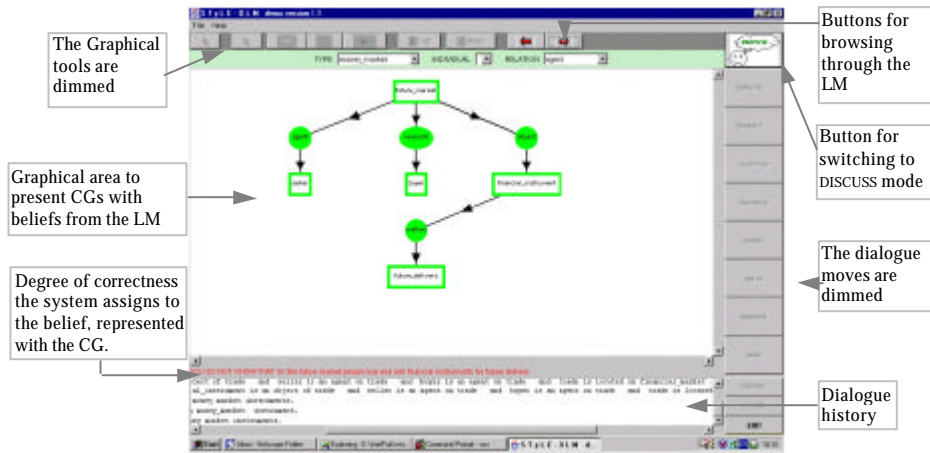


Figure 3. STyLE-OLM in BROWSE mode.

In BROWSE mode, a user is allowed to inspect the jointly constructed LM elicited from the discussion. As Figure 3 shows, the layout in this mode is akin to the DISCUSS mode but the graphical widgets are disallowed. The bottom line of the graphical area shows the level of correctness that the system assigns to the beliefs in the LM. The arrows on the top allow browsing backwards and forwards through these beliefs.

5 STyLE-OLM Used with Learners

An experiment with seven subjects, postgraduate students at the authors' department, was conducted to examine the behaviour of STyLE-OLM and to analyse advantages of IOLM [9]. We discuss here only the use of the communication medium focussing on pitfalls and potential improvements, see [6] for full details of the study. Each learner attended an individual session, prior to which he/she was given an introductory text with Finance terms to study for a while and then asked questions about these terms. The learners' performance was assessed and initial LMs obtained (by hand). During half an hour training, which included instruction and guided walkthrough interaction with STyLE-OLM, learners got acquainted with the interface.

In a session with STyLE-OLM, the learners were asked to help the system obtain a better picture of their domain conceptualisations, which would facilitate adaptability in pedagogical situations like generating explanations, providing feedback, and selecting instructional materials. The learners were encouraged to discuss their domain knowledge, inspect their LMs and influence the content of these models. Each interaction lasted about half an hour and was terminated by the users. All sessions were monitored by the experimenter. Learners were given a questionnaire at the end of the sessions and some of them were interviewed to clarify unexplained aspects.

5.1 Outcomes

The communication medium was adequate for discussing and inspecting the LM. The participants did not experience major problems with constructing and understanding dialogue moves as well as examining LM beliefs in the LM.

Understanding Propositions Rendered in a Graphical Manner. At the beginning of each session, the learners mainly read the text shown in the bottom of the graphical window. After a while they became more confident with the graphics and in most cases examined both the CGs and the textual equivalents generated by the system. Although many learners found it useful to have both text and graphics to represent domain facts, it was often the case that the text was confusing (STyLE-OLM uses a simple template mechanism to generate sentences from CGs). Most learners commended the graphics when seeking to understand domain facts both in the system dialogue moves and the learner model. They found such representations helpful for articulating the main concepts and relations between them.

A major problem with the LM inspection concerned navigation. Learners usually switched to a BROWSE mode to search for information about the last stated fact, in order to see how their statements changed the LM or how the system assessed the correctness of these statements. Finding a particular graph in the LM often required considerable browsing through the LM. It seems beneficial to re-organise the beliefs in the externalised LM so that recently discussed ones appear first and provide search facilities so that beliefs related to a particular concept can be selected.

Constructing Propositions with Conceptual Graphs. Learners' opinions about the expressive power provided in STyLE-OLM to construct dialogue utterances varied. Some learners found the interface "a little idiosyncratic and non-standard" which "takes a lot of getting used to". Problems here refer mainly to changing graphical objects, selecting propositions, invalidating the last action, and spending much effort on finding terms. Although these issues do not demote the overall approach, they indicate the need to improve the user-friendly interface features.

Some learners experienced problems with justifications: to justify they needed to construct a new CG and select a sentence opener 'BECAUSE' - the statement being justified could potentially be lost and the argument obscured. For example, if after a system's challenge 'Why do you think that G ', the learner justifies with 'It is true because G_1 ' (where G and G_1 express propositions represented with CGs). The learner's utterance does not have an explicit link to the statement he justifies and may obscure the understanding of the argument, for example, when reading the dialogue history. To address this problem, the CG language employed needs to incorporate contexts [17]. Contexts may bring more complexity for the graphical language. Further investigation is needed in order to utilise them in a communication medium.

The limited number of relations provided was the major obstacle for learners when constructing CG statements. There are two types of relations in STyLE-OLM - basic relations, such as 'agent', 'characteristic', etc. in line with [17] and domain oriented relations, such as 'operate_with', 'provide', 'trades_with', etc., identified by a Finance expert. The learners searched mostly for links of the second type and complained about missing relations (but rarely identified which ones). They seemed disappointed to be trapped in a language environment where very few verbs were provided. A proper expansion of the list of domain relations is required. The study

also enabled us to identify sets of confusing basic relations, such as {actor, agent}; {patient, object, recipient, instrument}; {characteristic, attribute}; {operate_with, trade_with}; {support, provide}; {isa (in the meaning of part_of), contain}.

The participants in the study did not agree regarding their choice of graphics or text. The study is too limited to discuss this issue deeply, and further exploration is needed. In this line, [4] 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 need examination in respect to LM inspection and discussion).

6 Conclusions and Future Work

This paper presents the design and implementation of a communication medium for IOLM. Such a medium provides a means for learners to inspect and discuss the models the system builds of them. Based on relevant research, we have justified an approach of inspecting and discussing the LM in a graphical manner using conceptual graphs. We have presented an empirical study that examined whether people can read, build, manipulate and communicate with conceptual graphs. The study has informed the design of a communication medium for IOLM. Recommendations drawn from the study have been taken into account in the implementation of the communication medium in the STyLE-OLM system - an IOLM demonstrator in a terminological domain. We have presented the implementation of the communication medium in STyLE-OLM and have discussed its potential and possible improvements on the basis of an evaluative study of STyLE-OLM.

The paper illustrates a favourable application of a methodology found in Human-Computer Interaction research to the design of a communication medium in learning environments. The medium has been designed based on theoretical justification and empirical investigation, it has then been implemented and validated in a study with genuine learners, which has highlighted further improvements.

The work presented here is a step in a promising way forward to building learning environments that provide learners with control over the system's behaviour. It also demonstrates the development of an effective communication medium that reduces communication problems, facilitates reasoning about a learner's behaviour, and promotes meta-cognitive processes. Such a medium can be utilised in a wide spectrum of intelligent tutoring systems that enable learners to inspect and communicate knowledge to the system (e.g. interactive tutoring systems, learning companions) or to other learners (e.g. peer diagnosis, collaborative problem solving).

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