SAIC: A Computational Approach for Supporting Children's Conceptual Understanding

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Abstract. The use of intelligent agents in tutoring systems has increased the importance of research in the area of student-teacher communication. Teachers usually interact interpersonally with their students to teach new concepts, especially in one-to-one tutoring, and effectively support the conceptual understanding of the students at the concrete operational stage. This paper presents SAIC (Schema Activation and Interpersonal Communication): an architecture for designing interactive agents based on schema theory and interpersonal communication. We discuss the formalisations of schema theory-based dialogue and cognitive processes which are required to produce computational models of the processes.

Introduction

The use of computer technologies, such as multimedia tutoring systems, in classrooms can provide stimulating interactive environments for children to learn new concepts. Studies show that while in classroom settings human teachers effectively support children's conceptual understanding, computer tutors fail to communicate the intended meaning of words [1] and miscommunication may occur due to lack of effective teaching strategies and tactics. Human teachers are able to communicate the meaning effectively by appropriately relating new concepts to the prior knowledge of the students [2]. One possible methodology for designing intelligent tutors is to derive teaching strategies from theories of learning [4]. In the case of learning new concepts, theoretical models that explain the importance and use of children's prior knowledge are fruitful.

Interactive pedagogical agents are a new design paradigm for Intelligent Tutoring Systems (ITSs) to enable a dialogue interface between human students and computer tutors. They are employed in tutoring systems to provide a two-way communication that supports a student-centred and collaborative learning. However, the effectiveness of computer tutors may be hindered by their limited communication abilities [4]. To teach students intelligently, the agents need to communicate with students personally and adapt to their learning.

In this paper we propose a novel way of designing ITSs, based on an integration of schema activation and interpersonal communication (SAIC), to help children learn and understand new concepts while communicating with intelligent tutors. Our work aims to support the dynamic cognitive status of children who are at their concrete operational stage [8], through interpersonal communication. This proposed system architecture deals with the cognitive meaning-making processes and takes into account the children's prior knowledge. It is intended to act as a platform for the development of effective, dynamic and adaptive intelligent tutors that assist conceptual understanding in one-to-one student-tutor interactions.

The design of the SAIC architecture, which is the focus of our work, follows a specific ITS design methodology based on a mixture of theory and empiricism as described by Self [10]. The underlying ideas of the SAIC approach come from combining the schema theory [3] and an interpersonal communication model [5] from which we may formally derive design principles to describe the behaviour of intelligent tutoring systems. As Self discusses, at each development stage, empirical fine-tuning is required to ensure that the final systems will be developed as informed by the learning theory and its principles [10].

In the following sections we give a detailed account of our approach. In section 3, we exemplify the approach in a prototype. In section 4 and 5, we describe initial attempts to formalise the computer tutor-student interaction and cognitive processes respectively. Finally, section 6 concludes with the expected contribution of our work.

2. The SAIC Agent Approach

We propose SAIC (Figure 1) as an extension to traditional multimedia systems. New functionality in terms of an intelligent pedagogical agent is added to enable a multimedia system to communicate with a child and explain concepts based on schema theory. Figure 1 presents the proposed architecture. A cognitive model of the learner is employed by the intelligent agent to communicate dynamically and adaptively with the learner in order to help him or her acquire new domain concepts. The intelligent agent continuously updates the model when it interacts with the child. The model represents the current development stage of the child and accumulates schemas about domain concepts that the child has created.

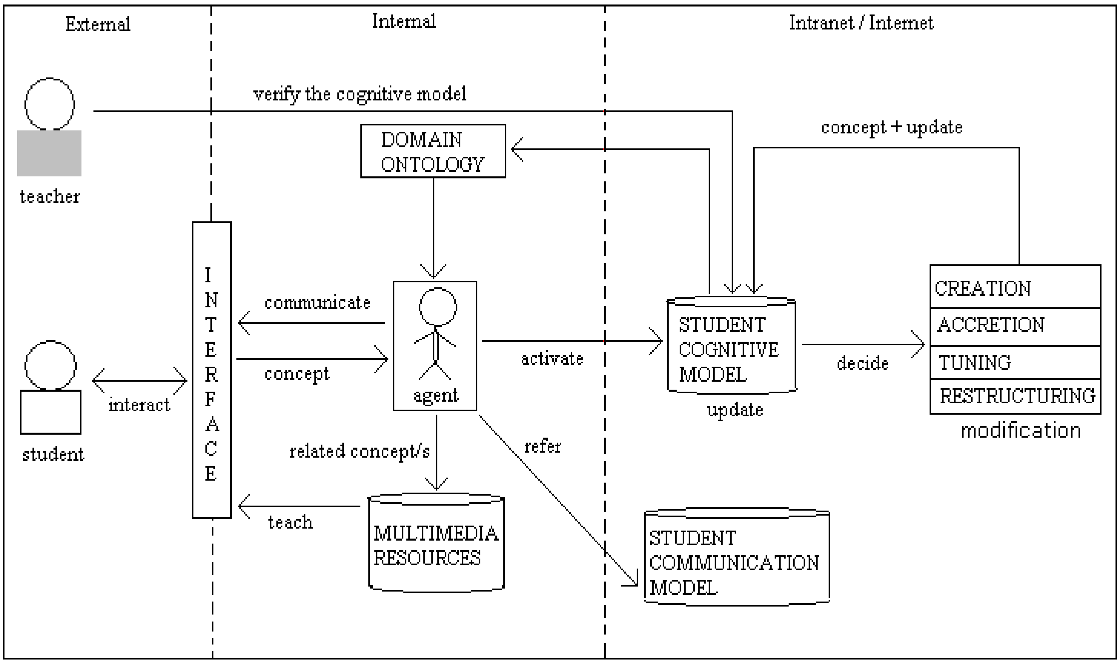

Figure 1. Architecture of the proposed system

This figure shows that the student interacts with the interface to learn new concepts. The system presents new concepts to the student in the form of texts and graphics. The pedagogical agent receives the new concepts and activates the prior knowledge of the student to find relevant schemas. The agent needs to decide what to do with those schemas in the modification process [9] in order to help the student understand the new concepts. By referring to the student communication model and using the domain ontology, the agent communicates with the student to explain the new concepts.

The extension to conventional intelligent multimedia educational systems following the SAIC architecture is in the form of the following components:

- *Pedagogical agent.* This agent communicates textually and graphically with the student to explain new concepts. The focus of the SAIC architecture proposed here is on the design of effective pedagogical communication by following the principles of schema theory. For the sake of simplicity and keeping the research focused, our work considers certain patterns of textual inputs from expert human teachers and does not attempt to analyse free textual inputs. However, we examine a multimedia interaction mode that combines text and pictures to aid appropriate schema activation.
- *Student cognitive model.* It represents the prior knowledge of the student in the form of schemas. The cognitive model contains schemas learned by the student in his or her previous interactions with the system. They are acquired from a variety of lessons learned continuously and interactively by the student.
- *Schema modification.* The agent decides what to do with the relevant schemas activated from the student cognitive model in order to interpret the new concept. In other words, it has to choose which learning mode is appropriate in order to explain the current concept: creation, accretion, tuning or restructuring.
- *Domain ontology.* The agent explains the new concept based on the domain ontology that represents domain concepts and relations between them. The agent employs the domain ontology in its interaction with the student to have a mutual understanding of the concept.

3. Going to the Moon – Informative Design and Exemplification of the SAIC Architecture

In order to exemplify systems based on SAIC approach, we have designed an ITS prototype 'Going to the Moon' that introduces basic concepts in astronomy to children at the concrete operational stage [8]. It is an online educational software with a dialogue interface to *simulate* an interpersonal communication mode between a child and an agent.

The development of this prototype follows the guidelines of schema-based instruction outlined in [6]. The schema-based instruction can be decomposed into five parts:

- *Structure*. The overall structure of the lesson, a top-down view of the lesson.
- *Major components of the lesson*. The contents which are believed to be useful to understand the lesson as commonly included in other instructional formats, for example educational books, CD-based multimedia programs, and websites.
- *Relationships*. The relationships between the major parts.
- *Concepts*. They are the underlying concepts the students need to understand in order to understand the whole lesson.
- *Examples*. Ideas to help them understand the concepts. Students' reasoning at concrete operational level depends on concrete examples rather than abstract ideas [8].

'Going to the Moon' is a Web-enabled multimedia system built on a distributed client-server architecture. The main principles behind its web deployment are to have a broader audience and to ease the later updates. It is in the form of a downloadable ShockWave applet that contains the user interaction portion of the tutor and communicates directly with a server application using an inter-program communication program called Multiuser Server. At the moment, it is a conversion of the standalone tutor to one capable of operating over the Web. The next stage is to replace the human tutor with an intelligent agent based on SAIC.

Interaction with the current prototype needs simple skills of navigating and interacting with Web-browsers that eliminate the user interface component of the standalone application. However, the student-agent interaction can start only after the communication between the client and server is established.

4. Constructing the Communicative Part of the SAIC Agent

The goal of this section is to investigate a computational model of dialogue that can support effective interaction between a computer tutor and a student in terms of their collaboration to explain new concepts. Here we describe a framework to construct the communicative part of SAIC agent from example dialogues. For collecting the example dialogues, we used our prototype and conducted Wizard of Oz experiments. The dialogues are based on schema activation and modification scenarios, and held between a child (simulated by the first author) and expert human teachers from Malaysia.

We have analysed the dialogues and identified the communicative acts employed by human teachers to explain new concepts to students. The analysis of the communicative acts gives us valuable insights of the teaching strategies used human teachers to perform schema activation and modification, and how they interactively teach new concepts using dialogue. Based on the analysis, we have classified the communicative acts into scenarios that represent the cognitive processes in line with the principles of schema theory. Examples of communicative acts and their matching scenarios are shown in figure 2.

Communicative Act	**Cognitive scenario**	**Example from the dialogues**	**Teaching strategy**
1- Ask	Activate	I want to ask you simple questions about the rocket	Provide background knowledge to start the lesson.
2- Compare	Accretion	Rocket flies like an aeroplane	Show main similarities between two concepts.
3- Differ	Tuning	Both aeroplane and rocket fly from one place to another. The rocket flies to the moon.	Tell the similarity and difference between two concepts to show what makes them different.
4- Contrast	Restructuring	Unlike car, rocket flies to the moon	Tell the main properties of the concept
5- Inform	Creation	Astronaut goes to the moon using a rocket	Explain a new concept by relating it to other concepts in the lesson

Figure 2: Example of communicative acts, their equivalent scenarios and teaching strategies to explain the concept ‘rocket’ to children.

Using these communicative acts and sentence composition templates, the communicative part of the SAIC agent can generate restricted natural language to enable dialogue interaction with students. We have been formalising the dialogue using formal definitions of interaction patterns to produce a computable model that is executable in our prototype for simulation purpose.

5. Modelling the Schema Theory-Based Cognitive Processes

There may be deeper cognitive reasoning behind the tutor's activation and modification strategies. We want to model such reasoning in our tutoring system in order to inform its design. Using the activation and modification models, we want to investigate the schema activation and modification processes through computer simulation.

The main idea of schema theory is that people understand new concepts based on existing structure, which Bartlette [3] termed as schema. He regarded the learning process as an active effort after meaning. This idea, however, is too vague and general to be implemented in a tutoring system. Therefore, we require explicit models of the human teacher-student interaction and student's cognitive processes to inform the design of ITSs. To model the cognitive reasoning, we require a formal definition of both the cognitive and of the teacher-student interaction processes.

Here we use the activate scenario as an example to illustrate the formalisation process. To formalise the scenario, we adopt the notion of schema activation as introduced by [9]. The principle of the theory is that related schemas are activated to interpret a new concept. In our case, we have defined schema activation to represent the new concept selected by student and the search for the relevant schemas in the student's cognitive model. We represent the schemas in the forms of frames [7] that have slots to be filled by the values of the new concept. As an example of the formal definition of the activate scenario and its entities, the definition of activate is:

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activates(agent, existing schema) :-
        selects(student, domain, concept),
        relevant(properties, concept, existing schema),
        fills_slot(existing schema, concept).
where existing schema represents the prior knowledge in the form of frames.
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which means the agent activates existing schema to interpret a new concept if the student selects one of the domain concepts presented to him or her, if the agent can find a relevant schema in the student's cognitive model that share similar properties, and if the agent fills the slots of the concept with the values of the slots of the relevant schema.

6. Conclusions

In this paper we have proposed SAIC: a novel way of designing interactive ITSs based on schema theory and interpersonal communication. The design architecture shows how a pedagogical agent can support the conceptual understanding of children at the concrete operational stage in one-to-one tutoring interactions. To implement the teaching strategies based on the principles of schema theory into tutoring systems, we have developed computable models of the interaction, schema activation and modification.

Our work is expected to contribute to the ITSs research by providing a computational framework to handle dynamic and adaptive communications between human students and computer tutors, and to support meaning making and learning of new concepts.

This work is still in progress. We are now formalising the behaviour of the SAIC agent which will enable us to develop the agent and to incorporate it into "Going to the Moon". We then plan to verify the formalisations and evaluate the effectiveness of teaching strategies embedded in the tutoring system.

Acknowledgements

Thanks are due to the Majlis Amanah Rakyat (MARA), Malaysia, for sponsoring the research reported in this paper, and several teachers from Malaysia who have participated in the Wizard of Oz study.

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