A THREE-DIMENSIONAL PERSPECTIVE ON THE CURRENT TRENDS IN STUDENT MODELLING

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Abstract
Some of the recent research in student modeling is integrated in a three-dimensional space reflecting the important trends in the field. The dimensions are: levels of knowledge with respect to its ability to generate new knowledge, updating and organization. Within this space is shown the place of recent work concerning consistency maintenance, knowledge structuring and dynamic stereotypes, various levels of granularity, viewpoints and formal approaches to student modeling, as well as some still not addressed issues.

1 INTRODUCTION

Several classifications of user and student models have been developed in the 80's (Rich, 1983), (Sleeman, 1985), (Van Lehn, 1988). Though helpful for seeing the technical differences in the implementations of a number of student modelling prototypes, they can not be applied to most of the recent research in student modelling. The reason is that their dimensions are intended to describe certain characteristics of implementations of the models rather than the underlying characteristics of the problem of student modelling and the approach of addressing it. A framework for learner modelling with more fundamental in this sense dimensions is proposed by Dillenbourg and Self (1990). Its aim is to introduce a formal notation and to show how various diagnostic techniques can be described with it. However, it is not intended to capture the recent research in student modelling.

The aim of this paper is to propose a space with new dimensions within which much of the recent research in student modelling can be consolidated. The dimensions are reflecting the author's view about of the forces underlying the changes of the focus of research interest. That is why the classification according to these dimensions can help to see certain trends in the history of this field and notice some unexplored topics of potential interest for future research.

2 NEW DIMENSIONS

The three new dimensions are:

<u>1) Levels of knowledge represented in the model.</u>

The knowledge contained in the model is intuitively considered as the most significant dimension (it is present in all classifications so far). Instead of discriminating between declarative and procedural types of knowledge (Van Lehn, 1988) or behavioral and conceptual ones (Dillenbourg & Self, 1990), we distinguish among models representing:

- evaluations of the student's performance;
- the student's beliefs;
- meta-beliefs;
- deductive mechanisms (logic);
- meta-logic.

In this way we can view every next level as an explicit representation of the knowledge needed to automatically generate knowledge of the previous type (e.g. by means of meta-beliefs modifications to the existing belief-set could be made; by means of deductive mechanisms new beliefs are generated). In our opinion one of the factors influencing the progress is the aim of researchers to represent explicitly knowledge needed to make the model generative, instead of enumerating all possible knowledge states in advance. By selecting the types of knowledge in this way, we ensure that every next type is "more-advanced".

2) Updating.

The updating of the model has two aspects:
- diagnosis of the student's knowledge and
- maintaining the model's consistency.

Diagnosis, or how the observed student's performance is interpreted into a set of beliefs is obviously very important when a practical system is implemented. That is why diagnostic techniques are present, as an implicit dimension in Van Lehn's classification and in Dillenbourg & Self's framework. Since diagnosis does not seem to be the main topic of interest in recent systems, this classification does not have a discriminative power with respect to diagnosis.

Maintaining the consistency of the belief set has not been considered as an important characteristic so far, but has become an area of active research recently.

3) Organization.

The structure of the model is an important characteristic with a big discriminative power for early models on the evaluations-level and for recent belief-level models. A distinction can be made among models:
- without any structure,
- with a fixed horizontal structure (stereotypes) on one level of knowledge,
- with a multi-dimensional structure on one level of knowledge based on different types of links,
- with a dynamic structure on more than one level of knowledge.

Of course, other dimensions could be defined, but these are orthogonal and suffice for our purpose. They allow us to consolidate a significant part of recent research in student modelling and to show the progress of the various approaches.

3 CLASSIFICATION, REFLECTING THE PROGRESS IN RECENT APPROACHES

The classification of several approaches with respect to how they address the three dimensions is shown in table 1. This section will give an idea of the reasons for a system falling under a certain category.

Table 1. (a, b, c). A classification of recent approaches according to the three dimensions.

a)

LEVEL UPDATING	**EVALUA-TIONS**	**BELIEFS**	**META-BELIEFS**	**LOGICS**	**META-LOGICS**
Diagnosis	profiles, GRUNDY	GUMS, WUSOR, PROUST, LISP-tutor	GUIDON	LISP-tutor PROUST ACM	REPAIR
Consistency		SMMS			REPAIR

b)

ORGANI-ZATION UPDATING	**WITHOUT STRUCTURE**	**1-DIM. STRUCTURE**	**MULTI-DIM. STRUCTURE**	**STRUCTURED ON DIFFERENT LEVELS , VIEWPOINTS**
DIAGNOSIS	LISP-tutor	GRUNDY, GUMS	WUSOR	plan recognition PROUST, ACM

CONSISTENCY	REPAIR	SMMS		

c)

ORGANI-ZATION **LEVEL**	**WITHOUT STRUCTURE**	**1-DIM. STRUCTURE**	**MULTI-DIM. STRUCTURE**	**STRUCTURED ON DIFFERENT LEVELS , VIEWPOINTS**
EVALUATIONS	profiles	stereotypes, GRUNDY	*****	******
BELIEFS	overlay, bug models	curriculum	conceptual, WUSOR, SMMS	****
META-BELIEFS	GUIDON			
LOGICS	LISP-tutor			
META-LOGICS	REPAIR			

Early approaches to student modelling typically make a shift only along one dimension. Recent research shows advance in all dimensions at the same time. As we are taking a historical perspective, we shall follow the advances along the dimensions separately.

3.1 ALONG THE FIRST DIMENSION

The first student models in CAI-systems and early ITSs were representing **evaluations** of performance (a single number, a vector of parameters, e.g. profile models). Combinations of parameters could form structures or stereotypes (Rich, 1983). No consistency maintenance could be done, since this suggested some knowledge about the meaning of the evaluated parameters, in order to encounter a conflict. All parameters describing the student had to be enumerated in advance and the corresponding action of the system had to be pre-defined. The question arose, whether it is possible to represent in an explicit form the **student's knowledge**, and thus to enable the system generate automatically evaluations or tutorial actions.

Almost all of the works in student modelling of the 70's and up to the mid 80's address this knowledge level. Although applied in different domains and claiming different paradigms (e.g. overlay- and bug-paradigms) they could be unified, if "**belief**" is introduced as a unit for knowledge representation. Then the distinction between enumerative and generative models can be seen clearly. Enumerative models have a pre-defined set of beliefs that cannot be changed while the generative ones are able to generate beliefs due to an (usually) implicitly built-in inference mechanism.

A further shift along the first dimension was made by Clancey (1982). He was perhaps motivated by the wish to enhance the generative capabilities with a respect to faulty belief generation. In GUIDON he represents a set of explicit **meta-rules** or **meta-beliefs** in the model that can be applied to change the existing base of rules and to make it generate errors. PROUST is an example of a diagnosis resulting in representation at a logic level. The system is inferring the plan of a student for solving a problem from the final solution, i.e. the strategy of combining rules. ACM (Langley & Ohlsson, 1984) presents another example for inferring the student's plan from a final solution by using Machine Learning techniques and a standard logic. If the logic presents a set of reasoning rules, a **meta-logic** presents even higher-level generative knowledge, a strategy for modifying or switching between different logics in order to solve a given problem. Van Lehn (1982) creates the REPAIR-theory, that can be considered as modelling the student at both the **logics** and at a meta- logics level, because it attempts to model an alternative reasoning mechanism.

3.2 ALONG THE SECOND DIMENSION

A lot of efforts were spent on inferring beliefs from observable student's performance (**diagnosis**) and almost no solutions have been obtained that could be generalized beyond the domain boundaries of the specific system. Some approaches, however, are very interesting. While trying to avoid computational problems in diagnosis, they make a step forward along the other dimensions. For example, Anderson & Reiser's (1985) "model tracing" approach was motivated by the need to limit the search space within a generative paradigm. They created a psychologically-based belief set that allowed the system to generate only beliefs that could be generated by real students. One could see in this the ancestor of a viewpoint (a belief set with a reasoning mechanism supposed to be shared by a certain population of students).

Until recently only short-term incremental student models were developed and maintaining consistency was only considered as a technical problem (Huang et al, 1991). However, if the student model is viewed as a set of beliefs, consistency becomes a principle problem addressed by a lot of AI-research (Self, 1991c). In case of conflicting beliefs the student can discard either the new belief, or one or more of the old ones. Which one should be discarded? This is the subject of a lot of research both in data-bases and AI. Two approaches for belief revision exist: coherence (to discard a belief only when it is challenged) and foundations (to discard unjustified beliefs). The REPAIR-theory could be viewed as an example of coherence approach for maintaining the consistency of the student's belief set. The foundations approach claims some psychological relevance and has been applied by (Huang et al, 1991).

However, keeping consistency in a big set of beliefs seems both to be not computationally tractable and psychologically justified. Students seem to be able to reason with conflicting beliefs in different frames of mind. Recent work on focus of attention in belief-revision (Greer and McCalla, 1991) assumes that only a small belief-set, relevant to the current focus of attention needs to be consistent at a time. An open question is, however, what criteria to use to select the relevant beliefs.

The student could be able to reason with an inconsistent belief-set by using a non-classical logic. Self (1991c) enumerates several limited reasoning mechanisms that might be appropriate. So, a progress along the first dimension is envisaged: creating a model on the logics level, in which several inference mechanisms are enumerated. The next step might be to generate such inference mechanisms by the use of a meta-logic.

3.3 ALONG THE THIRD DIMENSION

The first steps towards introducing a structure concerned the evaluation level. GRUNDY (Rich, 1983) has a pre-defined set of **stereotypes**, each one consisting of a set of evaluations of the user's personal characteristics. Diagnosis in this type of stereotypes is usually based on classification methods and no consistency maintenance is necessary, since the parameters in the stereotype varied within fixed intervals and no interrelations were accounted.

Structuring on the belief-level appears with the attempts to model conceptual knowledge. As pointed out by Huang et al. (1991), *"knowing a concept usually implies knowing some other concepts and not holding certain related misconceptions"*. **One-dimensional** curriculum-oriented structured models were developed (Peachey & McCalla, 1986) according to links of precedence. Two-dimensional belief-hierarchies were proposed by (Greer & McCalla, 1989) with respect to links of abstraction and aggregation. Goldstein (1979) and later Brecht & Jones (1988) develop a "genetic-graph", which is a **multi-dimensional structure** with respect to all fore-mentioned links plus analogy. Hierarchical structures of beliefs turned out to be very useful for coping with diagnostic problems because the appropriate level of granularity can be ensured (Greer & McCalla, 1989). It is a question to be answered by future research of whether it will be possible to find generative mechanisms for belief structures (to advance along the first dimension) and how to maintain consistency in structured belief sets.

A stereotype paradigm could be applied to a model of the student's beliefs as well (Kass & Finin , 1988). This brings the new idea of "default beliefs", i.e. beliefs that are neither observed nor inferred but are ascribed to the student because his stereotype suggests so. This can be viewed as one way of generating structured sets of beliefs within an enumerated set of constraints (the stereotypes). The subtle issue about the relevance between deductive and default knowledge and the dynamic selection of stereotypes seems ripe for research (Huang et al, 1991).

Generation of belief-structures could be expected to happen within **viewpoints**. A viewpoint could include structured knowledge on different levels. The belief-space, representing the student's knowledge can be divided into sub-spaces, each one with an associated limited reasoning mechanism, representing a student's viewpoint or frame of mind. As mentioned before, viewpoints could be the key for coping with maintenance of consistency in the belief base.

A question arises of whether all potential viewpoints need to be anticipated or may they be generated as needed by the system. We can expect that many generative mechanisms on different levels (logics, meta-beliefs and meta-logics) will be involved in generation or revision of a viewpoint. Some of these issues are relevant (Self, 1991c) to recent research on reflection in AI (Genesereth & Nilsson, 1987).

The student's learning could be represented in two ways. The first is enumerative - by consecutively adopting different viewpoints, as in White & Frederiksen's (1990) mental-models progressions. The second one is generative. "Knowledge negotiation" (Self, 1991b) is a complex reasoning process of combining different viewpoints, aimed at creating a more full and focused view on the topic. Self (1991c) points to many theoretical and practical difficulties to be overcome before the idea of viewpoints can be fully implemented. For example, we need efficient ways of identifying the student's working viewpoint. The diagnosis of viewpoints will prove very hard, if all levels of knowledge and their structure are considered dynamic (the beliefs and the reasoning mechanism).

A simpler task is to infer the student's viewpoint when the reasoning mechanism is fixed. A lot of research on plan-recognition, e.g. PROUST (Johnson & Soloway, 1985) addresses this issue. This task is reduced to a parsing problem with a set of primitive actions (symbols) and a fixed inference mechanism (the grammar). Perhaps some compromises with the generative paradigm will continue to be necessary in the near future.

Consistency maintenance within a viewpoint is recently recognised as an issue with important instructional implications. Usually people learn spontaneously when they get aware of the presence of inconsistency in their knowledge (a paradox, an improbable or undesirable fact). For example, the student's exposing to new information may cause knowledge negotiation with the agent's viewpoint (the teacher's). Some systems, exploiting the strategy of Socratic tutoring rely on this. However, no attempts to model the changes in the student's viewpoint have been made so far. An even more difficult problem will be to model the "internal" knowledge negotiation, when a conflict arises as a result of reasoning, because the belief that causes the conflict is not known.

However, the issues connected with knowledge negotiation between different viewpoints could be expected to get in the focus of research in student modelling in due course (Moyse & Elsom-Cook, 1991).

4 CONCLUSIONS

One can see that recent research shows advances taking place simultaneously in three dimensions. The development of multi-dimensional structures of beliefs, the integration of different types of knowledge into viewpoints, the issues of maintaining the consistency in generative models and knowledge negotiation will probably continue to be of high interest. It is obvious that they pose difficult problems, whose solution requires a sound theoretical background. Therefore, a big interest in formal approaches may be expected until the task of student modelling is put on a formal basis and a common language is established among researchers. Attempts for this are already being made (Self, 1991b). In the same time the focus of interest seems to move away from issues connected with diagnosis, perhaps because the solutions usually do not have the desired level of generality.

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