Supporting Learners in Adaptive Learning Environments through the Enhancement of the Student Model

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Abstract. This positional paper presents our research aimed at finding some possible research directions towards the enhancement of the use of open student models in the field of Technology Enhanced Learning and Adaptive Systems. Starting from the historical evolution of the learner model, we will describe some possible uses of learner models and propose some possible directions of enhancement. We will present 6 possible directions of research, and 11 dimensions on analysis. The 6 directions have been evaluated against the dimensions, and tentative ranking has been proposed. The result of this analysis will guide the work on open learner models which will be undertaken in the context of the European Union funded project GRAPPLE [1] aimed at building an infrastructure for adaptive learning systems that will adopt the strategy of opening learner models to the course learners and instructors

Keywords: Technology Enhanced Learning, independent Open Learner Model, Human Computer Interaction, adaptation.

1 Introduction

With the introduction of the new paradigm of personalized environments, the aspects of adaptation and personalization of computing systems to the users' characteristics, preferences, knowledge, and tasks are assuming a very central position in research. Strictly correlated to this aspect is the creation and updating of the student model [2], an important component of adaptive learning systems [3] that allows the system to adapt a course to the current learning needs of the learner, enabling it to offer a real, customized experience.

The student model maintains an accurate representation of a student's current state of knowledge, which allows the system to perform some adaptation based on the knowledge acquired during the learning process [4]. This internal representation of the student's knowledge, inferred by the system through an analysis of students interactions and results obtained in evaluation proofs (quizzes, assignments, ...), could also be used for other purposes, such as encouraging reflection by allowing the learner to inspect and, in some cases, modify the learner model [5].

J.A. Jacko (Ed.): Human-Computer Interaction, Part IV, HCII 2009, LNCS 5613, pp. 166–175, 2009.

This paper aims to explore the historical evolution of the student model, to identify the different approaches to model the level of knowledge of the learners and, based on this analysis, we will propose some possible directions of research on student models to support learners and encourage reflection in adaptive learning environments.

The motivation behind this research is that adaptive learning systems have been found to be useful in engaging the learner more in the educational experience [6]. The necessity to offer a higher level of commitment with the learning environment, especially when the most engaging human aspects inside these platforms are not so evident, became one of the key success factors for the wide diffusion of computer-based learning.

A large part of the research in the field of adaptive learning environments focuses mainly on providing the learner with a customized learning environment that adapts the content of the course to the user's knowledge and preferences [7]. These systems don't usually allow for the fact that the learner, besides being a user of the learning platform, is part of a "community of learners" (i.e. the class). A number of researches on social aspects of learning [8] stress the importance of the social interactions that occur during the learning processes. Our proposal aims to contribute to the research on adaptive systems by exploring some possible ideas to extend the adoption of user models. In this view, the open student model is not only an internal component of an adaptive system, but is also a useful source of information that can be stressed to enhance the user's commitment to the online learning experience.

The next section begins with an historical analysis of the state of the art in the field of student models. We have identified 6 directions of research that could be explored in the research of learner models with the aim of encouraging the learner to inspect his/her model, and promote reflection as learning. Then an analysis, driven by a rating system based on 11 characteristics, proposes the most promising idea which will be investigated in the context of the EU-funded project GRAPPLE [1].

2 Modeling Learners in Technology Enhanced Learning Environments

Our attention is drawn to the field of Technology Enhanced Learning environments. We believe that it is important to improve the user commitment and the effectiveness along the whole learning process undertaken by using these learning environments, while also considering the importance of education for humanity and the progress of civilization and science. We consider the application of adaptive features in learning systems particularly well-suited to achieving this goal.

From the literature, we have identified four different approaches to the use of student models in educational systems, which are listed in the following sections.

2.1 Internal Models

This approach, also known as "*close models*", was developed to build an internal representation of the learners' progress with the course, mainly to implement adaptive features. Research has been conducted on internal users and students models for a long time, with the aim of profiling the user in different domains and applications.

Internal modeling procedures collect data from the users' actions and feedback, store it in an internal database, and provide the input data that can be used by the adaptive functionalities for user data reasoning. The modeling process is quite complex and involves different steps: deciding and structuring the information to be collected, collecting raw data, scrubbing, extracting new information with reasoning rules, and, if necessary, updating existing data. Internal models are built for system internal use only, as a black-box component: neither students nor instructors have the possibility of exploring the contents of the student model.

2.2 Open Models

The idea of either partially or totally opening learner models to the learner for inspection was developed mainly to promote student self-reflection and awareness of the adaptive features of the learning environment.

The term "*scrutable user models*" was introduced by Judy Kay in 1999 [9]. The notion of scrutability is related to the possibility of the learners to scrutinize the model to see, not only what information the system holds about them, but also the process used by the system to collect the data about the learners and the inferences based on that data. It must be noted that scrutability concerns inherently convey a complementary but different view on personalization, which stresses upon the learner's awareness of the personalization process he/she is committed to. Recent insistence on scrutability or "*inspectable open learner models*" [10] advocate for explicit communication to learners of the pedagogical aspects framing the personalized learning experience designed for them by an adaptive learning technology. Student models can also be opened to peers, but this raises new problems, such as privacy, control over personal data, and trustworthiness of the system. One possible approach to deal with some of these problems presented is to distinguish between friendship networks and peers' groups. Users can decide which part of their profile to release in a named (or anonymous) form, and who is authorized to access this data representation (peer models). It could be observed that opening the models to peers can foster collaboration (with friends) and competition (with peers) [11].

2.3 Group Models

The recent achievement of the social network centrality into the social constructivist theory provides reasons to investigate models that take *social and group aspects* into account. Group modeling is a recent field of research, in which the learners are modeled as a group instead of a set of single individuals. These model the characteristics of an identified group of learners, and aim also to present the position and the relative distance of profiles, in order to allow learners to compare and understand their own situations. Opening group models to the users may offer some advantages. It can help learners to reflect on their progress in the group context and understand the problems of other group members [12].

Group models have been used to support the collaboration between learners of the same group, and to foster competition in a group of learners [13]. Right now, only simple methods have been used to mine the group models. The most common is using the average individual values representing a particular aspect considered in the model.

2.4 Interactive Models

Interactive models introduce some levels of interactivity that can be expressed in two ways: the first, called *inspection methods*, is the capability to manipulate the graphical representation of the model, change the appearance, apply filters to the visualization and thus achieve a more in-depth understanding of the model. The other option, called *interactive methods*, is the possibility to influence the model, both by changing the data used by the system to represent the user itself, or by challenging and convincing the system that the current profile doesn't represent the learner status well. In this case, one problematic aspect could be the verification of the real understanding that the user has of the model, and which data support the claim for changing the internal profile according to the user request. Some systems tackle this problem by using a challenging process: they ask learners to solve a problem related to the particular aspect that should be changed and decide if this modification will be done based on the performance reached by the learner in this process. In the next section we will take the most interesting aspects from each of the previously described modeling approaches into account, and will investigate how they could be extended with input from other fields to provide the user with a better experience.

3 Extending the Use of Open Learner Models

Traditionally, research on Open Learner Models (OLM) has been carried out by scholars active in adaptive systems and educational technologies. This is evident as the main OLM applications are in adaptive systems. However, we believe that contributions from other fields of research could be beneficial to extend and improve the adoption of OLM. For instance, one of the key issues in OLM is how to graphically represent the model; techniques from Information Visualization could provide indications on how to select and encode data in a graphical format suited to the representation task of the user. Another aspect is how to aggregate information and find correlations between data; techniques from artificial intelligence could help in this aspect. Other useful works carried out in different educational research could be adopted in student models. For example, Glahn et al. [14] propose the adoption of “smart indicators” as a way to aggregate user model information in a compact and intuitive way through a visual indicator that draws attention to ongoing relevant events only when really necessary. Erickson & Kellogg [15] at IBM T.J. Watson Research Center propose the “social translucence” idea as an approach to designing systems that support social processes: socially translucent systems are digital systems that “*support coherent behaviour by making participants and their activities visible to one another and they have three main characteristics—visibility, awareness, and accountability—which enable people to draw upon their experience and expertise to structure their interactions with one another*” [15, p.59].

More specifically, works from other disciplines have led us to identify some possible directions of research for OLM:

P1 **Positioning the learner with respect to the class or to a group of learners.** This aims to use the OLM as a tool for supporting socialization, by making the student aware of the social context in which the learning experience is taking place, as suggested by the social translucence theory of Erickson & Kellogg [15].

P2 **The introduction of innovative graphical interfaces.** Contributions for Information Visualization [16] may help in investigating how to design innovative graphical interfaces, in order to reduce their complexity and the cognitive load required to interpret the underlying data, and adopt interaction techniques that enable the exploration of different aspects of user data.

P3 **The representation of the temporal evolution of the model.** The student model is not static, it changes as the student performs any action in the learning environment. A research work could explore whether opening this dynamic evolution of the learner model could be beneficial to the students (or to the instructors).

P4 **The use of adaptive representations of OLM.** An initial attempt to introduce some of the ideas of adapting the graphical representation of OLM comes from the work on "smart indicators" by Glahn et al. [17]. The idea is that the introduction of adaptive features in the graphical representation could help students to perceive the OLM in a more meaningful way. This allows the production of more engaging and effective external representations of OLM, and could provide a better experience to the users of the learning applications.

P5 **The exploration of techniques that allow the definition of a global student model, by integrating different independent student models** from different courses. Traditionally, student models keep track of the learner's knowledge and the skills acquired during the learning process on a course basis. Although a learning platform may run different courses, and students can enroll in several courses, each course has an independent student model. This is primarily due to practical, as opposed to theoretical, reasons: it is very hard to define a global ontology that models the concepts for several courses.

P6 **The introduction of a metric**, a function that defines a "distance" between students, based on the data stored in the learner model. This also allows the identification of groups of students having similar profiles.

Proposals P1, P2, P3, and P4 deal with an externalization of one or more aspects of the learner model, where the information is related to a specific course. P5 and P6 deal, instead, with more complex subjects: the creation of a global model of the user (P5) and the definition of a metric to measure the distance on learner models (P6) are very complex tasks for which research is still in the early stages. P5 and P6 are possible through data mining techniques, that work mainly with student tracking data (logs) to extract relations between data and can work even if a global model of the domains of the courses is missing [18].

In order to investigate how the research directions specified above could be effective in the learning process, we have identified a number of dimensions of analysis. These dimensions take into account the level of difficulty in implementing the idea, the difficulty in managing the new functionalities proposed, the expected impact at the system level, and the estimated benefits offered to the student in terms of the metacognitive skills that can be acquired. The dimensions that we have considered are:

D1 To what extend does this research enhance socialization among students?

D2 How much effort is required for the knowledge extraction and for reasoning over the data?

D3 The computational complexity needed to maintain the model.

D4 The difficulties in identifying one or more metrics.

D5 The granularity of representation of the problem space (continuous, stepped or discrete) [16].

D6 The amount of data required to have a reliable model.

D7 The difficulty in identifying the most useful data to collect and the level of aggregation.

We also propose other dimensions of analysis, which are more related to the experience, interaction, and mental model of the learner:

D8 The novelties and the benefits introduced by the new graphical interface.

D9 The impact on the cognitive load of the learner caused by the new information presented and the new way of presentation.

D10 The complexity of the rules that drive the creation of the model and the speed of their convergence into a stable state.

D11 The level of interactivity and the interaction type (continuous, stepped, passive or composed) [16].

4 Analysis of Proposed Dimensions

To investigate which dimension seems useful for exploration in our EU project Grapple, we have created an evaluation space and divided it into 4 areas. Each area represents an aspect that we would like to stress: the social aspects that can be influenced, the innovation in the graphical user interfaces that a research approach may bring, a representation of the temporal evolution, and the clustering of data that comes from learner models. The first step was an identification on the 4 areas of the 6 proposed directions of research (see Fig. 1).

In order to identify which proposals among P1 ... P6 are the most promising and worth investigating, we decided to set up a ranking system based on the 11 dimensions (D1 ... D11) defined previously. These dimensions were used to rate every proposal according to a 5 level scale (from *a* to *e*). Since some dimensions describe positive aspects (such as enhancing socialization, D1) and others denote problematic aspects (such as the computational complexity needed to maintain the model, D3), we divided them into two groups (D1, D5, D8, D11 and D2, D3, D4, D6, D7, D9, D10) and rated them using a direct scale (e is the highest value in the scale)

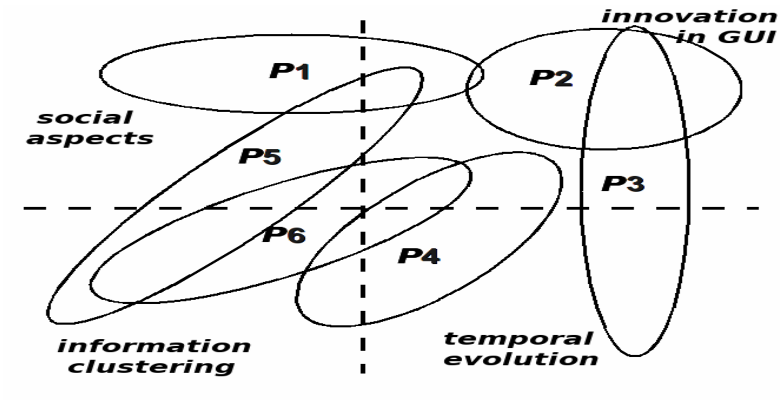

Fig. 1. The projection of the 6 proposals on a 4-area evaluation-space

for the first group and a negative one (*a* is the highest value in the scale) in the second. Then, each proposal P1, ..., P6 has been matched with each dimension D1, ..., D11 and the match has been empirically assigned with a value in the scale (*a* ... *e*) by a team of experts in educational technology at the laboratory of eLearning at the University of Lugano. The result of this exercise is illustrated in Table 1. This table is also used to derive a sort of ranking among the different proposals (columns Pos).

Table 1. Matching proposals against dimensions

	D1	D5	D8	D11	Pos	D2	D3	D4	D6	D7	D9	D10	Pos	Tot
P1	*a*	*c*	*d*	*e*	***3***	*b*	*c*	*a*	*b*	*c*	*c*	*d*	***2***	**2**
P2	*e*	*a*	*e*	*e*	***6***	*a*	*b*	*a*	*a*	*d*	*c*	*e*	***1***	**3**
P3	*d*	*d*	*c*	*e*	***5***	*d*	*d*	*d*	*d*	*e*	*e*	*e*	***6***	**6**
P4	*e*	*a*	*a*	*b*	***1***	*d*	*b*	*a*	*c*	*c*	*b*	*d*	***2***	**1**
P5	*c*	*c*	*d*	*c*	***3***	*d*	*e*	*d*	*e*	*c*	*e*	*d*	***4***	**3**
P6	*b*	*a*	*d*	*c*	***2***	*e*	*d*	*e*	*e*	*c*	*e*	*c*	***5***	**3**

The data shown on Table 1 has been visually encoded into a star plot graphical representation [19].

From the visualization depicted in Fig. 2, according to the findings on dimensions defined in Table 1, the proposal P4 (The use of adaptive representations of OLM) and P1 (Positioning the learner with respect to the class or to a group of learners) appears to be the most promising.

After this analysis, we decided to concentrate our work on the direction of introducing graphical interfaces adapted to the learners' characteristics stored in the learner model. Moreover, we want to integrate some support for social aspects in our work, such as the positioning of learners in the class or group (P1). The final two proposals (P5 and P6) are very interesting from the point of view of possible

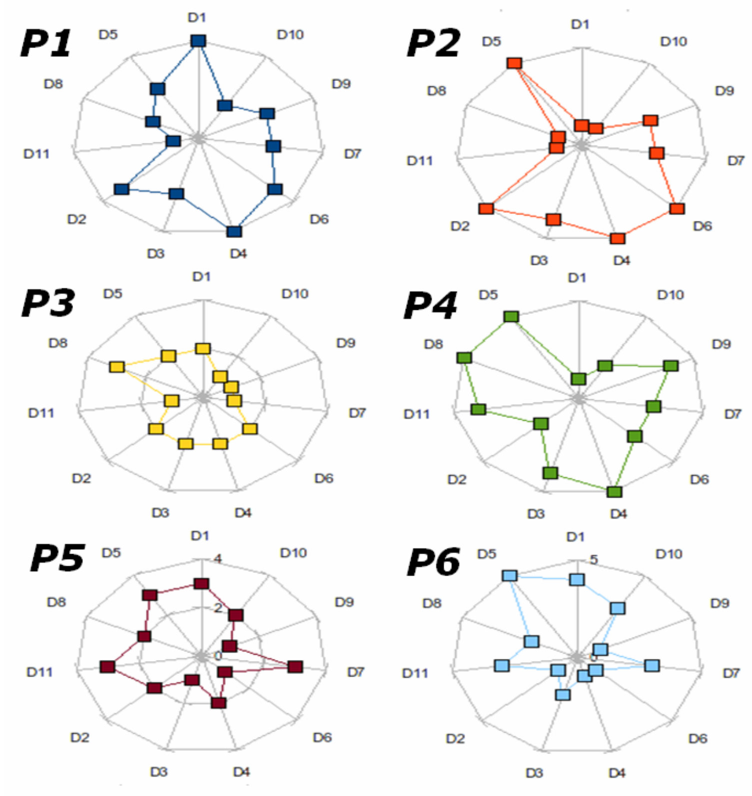

Fig. 2. Star plot of analysis dimensions for every proposal

outcomes in the user experience, pose a great number of open issues and will be classified as possible research extensions of this work.

5 Conclusions

We have analyzed some possible research directions towards the enhancement of the use of open learner models in the field of Technology Enhanced Learning and Adaptive Systems. The aim of this study was to identify, among a list of possible research directions, the most promising according to a list of 11 dimensions. The proposals of research have been evaluated against the dimensions, and a tentative ranking has been proposed. We located the most promising and plan to explore them in the context of the EU-funded project GRAPPLE.

A further aim of this paper was to stimulate the cooperation of researchers from different disciplines. The research directions proposed in this paper had the specific purpose of collecting feedback and asking other researchers to share their experiences and to foster collaboration.

We believe that this work could help, as an initial seed, to lead to a self-analysis by researchers into the improvements that could bring Personal Learning Environments to a new level of commitment and awareness in the users' experience.

Acknowledgments

This work was supported by the 7th Framework Program European project GRAPPLE ('Generic Responsive Adaptive Personalized Learning Environment'). The first author wishes to thank all of his colleagues and the coordinators of the Ph.D. School Red-Ink at the University of Lugano, as well as the researchers involved in the NewMinE lab and the eLab at USI for the interesting and useful discussions and ideas provided.

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