Chapter 15
Open Learner Models

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Abstract. An Open Learner Model makes a machines' representation of the learner available as an important means of support for learning. This means that a suitable interface is created for use by learners, and in some cases for others who aid their learning, including peers, parents and teachers. The chapter describes the range of purposes that Open Learner Models can serve, illustrating these with diverse examples of the ways that they have been made available in several research systems. We then discuss the closely related issues of openness and learner control and the ways that have been explored to support learning by making the learner model available to people other than the learner. This chapter provides a foundation for understanding the range of ways that Open Learner Models have already been used to support learning as well as directions yet to be explored.

15.1 Introduction

Open learner models are learner models that can be viewed or accessed in some way by the learner, or by other users (e.g. teachers, peers, parents). Thus, in addition to the standard purpose of the learner model of maintaining data to enable adaptation to the individual according to their current learning needs, the learner model contents can also be of direct use to the user.

There are a variety of ways in which a learner model might be helpful to the learner, identified in the SMILI☺ (Student Models that Invite the Learner In) Open Learner Modelling Framework (Bull et al. 2007) as:

- Promoting metacognitive activities such as reflection, planning and self-monitoring;
- Allowing the learner to take greater control and responsibility over their learning, encouraging learner independence;
- Prompting or supporting collaborative and/or competitive interactions amongst groups of students;
- Facilitating interaction between learners and peers, teachers and parents;
- Facilitating navigation to materials, exercises, problems or tasks, etc., where links are available from the learner model;

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- o Supporting assessment - in particular providing formative assessment opportunities for students, but also enabling the learner model to be used as a summative assessment;
- o Increasing the accuracy of the learner model data if the user is allowed to contribute additional or corrective information, to enable a more precise adaptive interaction to follow;
- o Increasing learner trust in an adaptive educational environment by showing the system's inferences about their knowledge;
- o The (non-educational) issue of people having the right to access electronic data about themselves.

A learner model that is inferred using any learner modelling technique could potentially be opened to the learner, if viewing the information in their learner model may be of benefit to the user. For example, learner models have been opened in simple weighted numerical models (Bull et al. 2009), fuzzy models (Mohanarajah et al. 2005), constraint-based models (Mitrovic and Martin 2007), Bayesian models (Zapata-Riviera and Greer 2004), transferable belief models (VanLabeke et al. 2007), knowledge tracing (Corbett and Bhatnagar 1997), and models constructed using conceptual graphs (Dimitrova 2003). The modelling technique does not necessarily determine the form in which the learner model will be presented to the user, or the level of interactivity the learner can have with their learner model.

Similarly, learner models can be opened in a variety of domains. As with adaptive learning environments that do not open the learner model to the user, they are often in programming (Weber and Brusilovsky 2001), mathematical (VanLabeke et al. 2007), scientific (Zapata-Riviera and Greer 2004) or second language (Bull and Pain 1995) domains. However, in line with increasing interest in less traditional domains in the field of artificial intelligence in education, open learner models are also becoming available in a broader selection of subjects. Examples include music theory (Johnson and Bull 2009) and historical text comprehension (Grigoriadou et al. 2003). Domain-independent open learner models have also been developed (Brusilovsky and Sosnovsky 2005; Bull et al. 2008; Mazza and Dimitrova 2004; Rueda et al. 2003; Kay and Lum 2005; Czarkowski et al. 2005). Furthermore, learner model attributes presented to the learner are not only cognitive, but may also include, for example, affective or social attributes (Chen et al. 2007).

In this chapter we give an overview of the presentation of open learner models, including common and less-traditional learner model externalisations; user/system control of the learner model and learning; and learner models open to other users such as peers, instructors and parents.

15.2 Presentation of Open Learner Models

Opening the learner model generally involves more than simply showing the learner the representations from the underlying system's model of their knowledge (or other attributes modelled), as these representations are not usually designed for interpretation by humans. In particular, learner models may not be designed for interpretation by those who are still learning a subject. While there is a case for ensuring that the underlying representation is designed explicitly to support the valuable roles that the open learner model can provide, this has generally not been the approach adopted. Regardless of the internal representation, a key challenge in opening a model to serve one of the purposes listed above, is to create an effective interface for presenting the model and supporting interaction with it.

As noted above, the method of model presentation does not necessarily match the underlying complexity of the model. For example, simple learner model overviews in the form of skill meters have been used to display a learner's knowledge level in a constraint-based model (Mitrovic and Martin 2007) (Fig. 15.1), and in a simple weighted numerical model (Ahmad and Bull 2009) (left of Fig. 15.2). Moreover, the complexity of a view of the learner model may differ within a system. Figure 15.2 shows both skill meters and a structured view of the learner model data available to the user in a single system (colour of nodes shows level of knowledge in the structured view) (Ahmad and Bull 2009).

Skill meters are the most commonly used simple overviews of the learner model contents, with a meter assigned to each topic or concept, which may include separate skill meters for sub-topics. (The latter allows simple structuring in the model presentation - e.g. Weber and Brusilovsky 2001.) Most skill meters show the level of the user's knowledge, understanding or skill as a subset of expert knowledge (Weber and Brusilovsky 2001), (Papanikolaou et al. 2003). The two examples in Figures 15.1 and 15.2 additionally show: (i) level of understanding as a proportion of areas covered (Mitrovic and Martin 2007); and (ii) the proportion

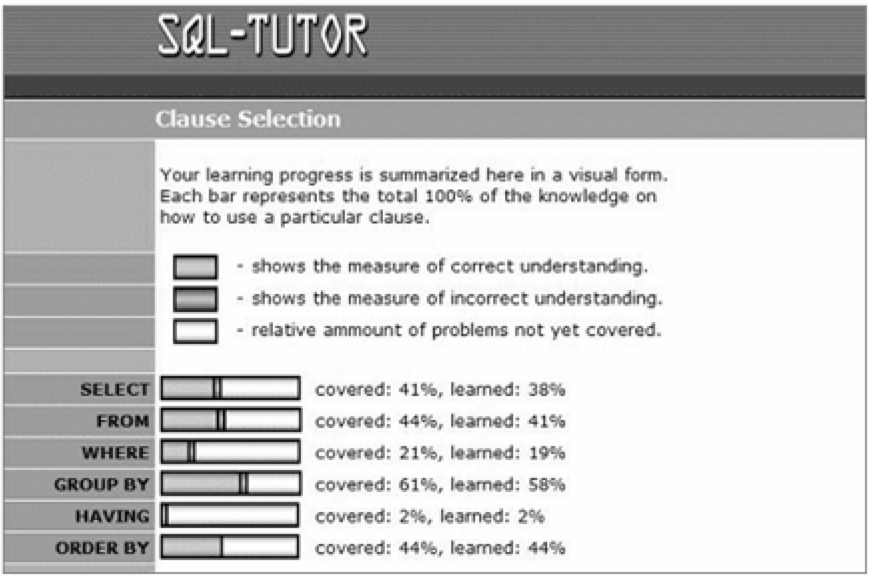

Fig. 15.1 Skill meters in SQL Tutor (Mitrovic and Martin 2007)

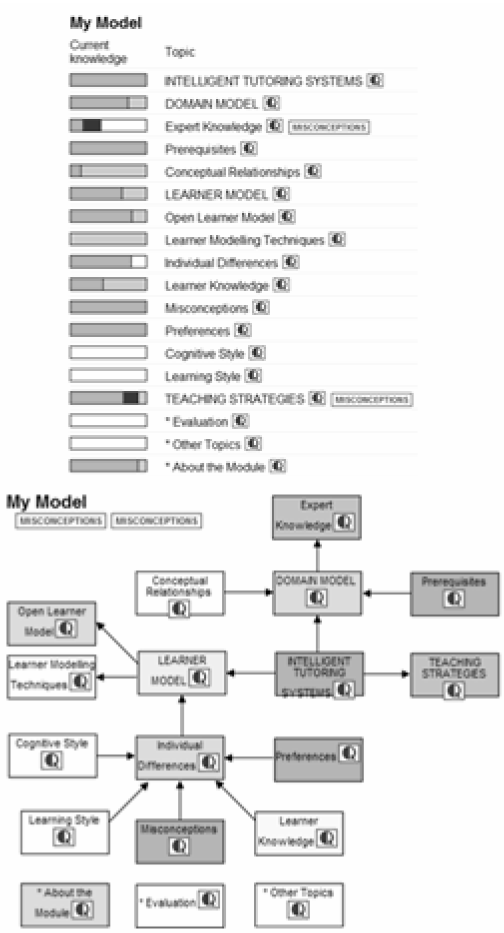

Fig. 15.2 Skill meters and structured view in OLMlets (Ahmad and Bull 2009)

of areas of difficulty that can be attributed to specific misconceptions (dark shading – clicking one of the misconceptions boxes presents a text statement of the specific misconception) (Bull et al. 2008). Other extensions to the standard skill meter are possible, e.g. varying the length of the meters to reflect the relative size of each topic (Bull et al. 2003); the skill meter showing the probability that the user knows a concept (Corbett and Bhatnagar 1997); or the level of knowledge of a learner contrasted against the combined knowledge of other groups (Linton and Schaefer 2000). Other representations that show similar information to the overviews displayed by skill meters for topics and concepts include: number of arrows in a target (Brusilovsky and Sosnovsky 2005); amount of liquid in a cup/container (Papanikolaou et al. 2003); smiley faces (Bull and McKay 2004); and images of the growth of trees (Lee and Bull 2008) (Fig. 15.3).

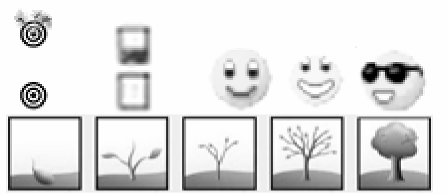

Fig. 15.3 Arrows in a target (Brusilovsky and Sosnovsky 2005); level of liquid (Papanikolaou et al. 2003); smiley faces (Bull and McKay 2004); and trees (Lee and Bull 2008)

The most common type of structured open learner model is probably the concept map (e.g. Rueda et al. 2003; Perez-Marin et al. 2007; Mabbott and Bull 2004; Kumar and Maries 2007), illustrated in Figure 15.4 by Willow (Perez-Marin et al. 2007) and Figure 15.5 by Flexi-OLM (Mabbott and Bull 2006).

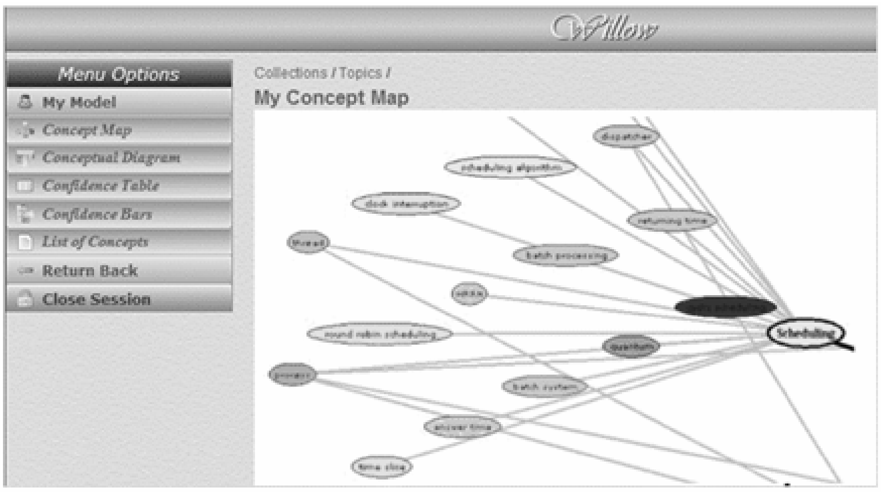

Fig. 15.4 The Willow concept map (Perez-Marin et al. 2007)

Concept maps can be pre-structured to reflect the domain, with nodes indicating the strength of knowledge or understanding of a concept (Mabbott and Bull 2004); they may reflect the learner's own conceptual structure or model, as inferred by the system (Perez-Marin et al. 2007); or they may be constructed by the learner (Cimolino et al. 2004; Mabbott and Bull 2007). Other detailed open learner model structures include tree structures, illustrated in Figure 15.6 with hierarchical structures in UM (Kay 1997) and Flexi-OLM Mabbott and Bull 2006); and individual instances of other types of structural relationship, e.g. Zapata-Riviera and Greer 2004; VanLabeke et al. 2007; Dimitrova 2003 (Fig. 15.7).

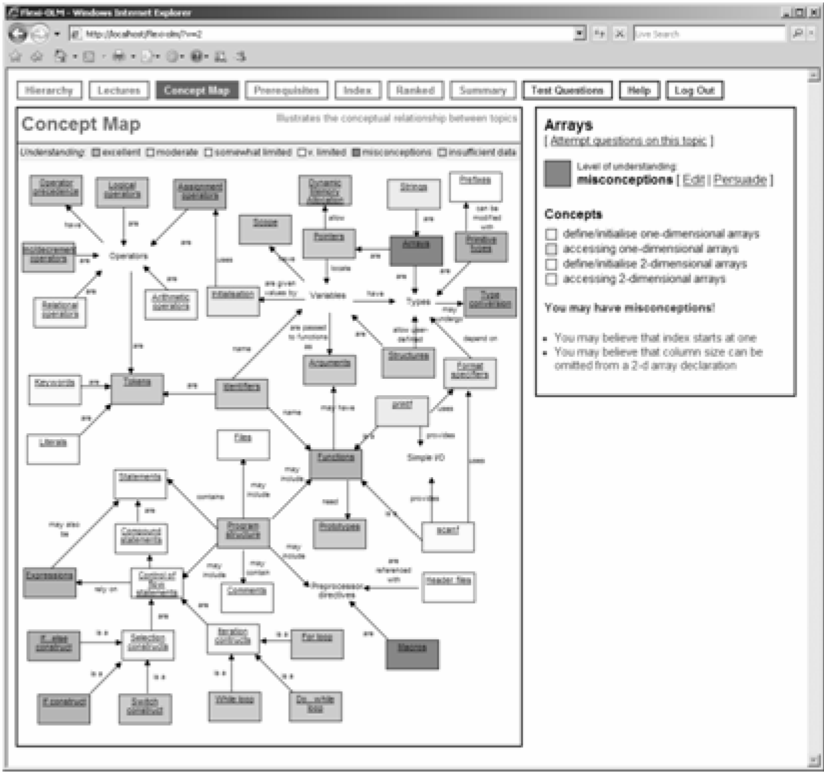

Fig. 15.5 The Flexi-OLM concept map (Mabbott and Bull 2006)

Consideration needs to be given to cases where detailed complex or structured learner model information is to be presented to the learner. UM (Kay 1997) (left of Fig. 15.6) allows the learner to expand and contract nodes to accommodate this requirement; SIV (Kay and Lum 2005) uses size, position and colour of text to display a large amount of learner model data (left-hand panel of Fig. 15.8). (Other uses of text in open learner models include Mohanarajah et al. 2005; Bull and Pain 1995; Tchetagni et al. 2007.)

Work has also investigated less traditional learner model presentations, including:

- audio and domain-specific representations for open learner models – e.g. MusicaLM (Johnson and Bull 2009) provides learner model information to the learner using a text description of learner beliefs, but also audio (music notes) and music notation (Fig. 15.9);
- haptic feedback in an open learner model, where strength of knowledge is portrayed by the 'hardness' or 'softness' of a sphere representing each area of the domain, and misconceptions feeling 'soft and sticky' (Lloyd and Bull 2006) (Fig. 15.10);

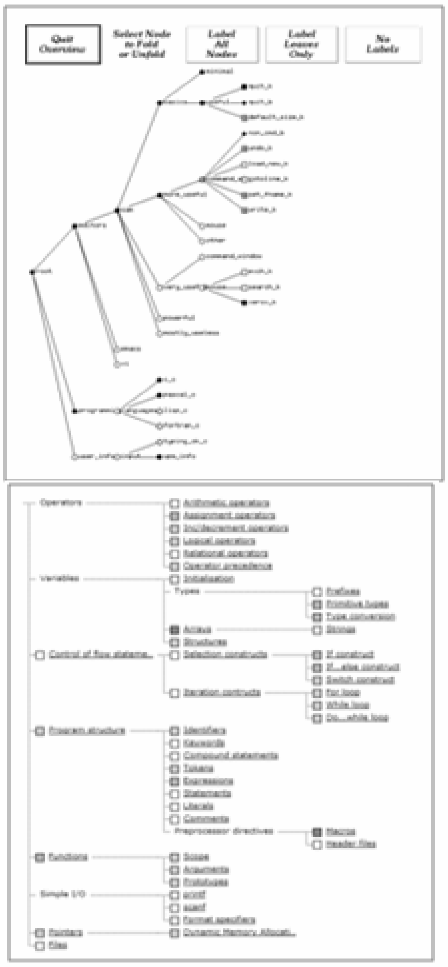

Fig. 15.6 Tree structures in UM (Cimolino et al. 2004) and Flexi-OLM (Mabbott and Bull 2004)

- open learner models for simulation tasks, such as the operation of a pole and cart device simulator (Morales et al. 2001) (Fig. 15.11);
- animations of a learner's misconceptions for comparison to the correct domain concepts, currently implemented for programming and chemistry (Johan and Bull 2009) (Fig. 15.12).

In addition to learner models that contain a single view of the learner model data, systems can offer multiple views of the same (or similar) model data for learners to explore (as many as seven views have been available in a system, with

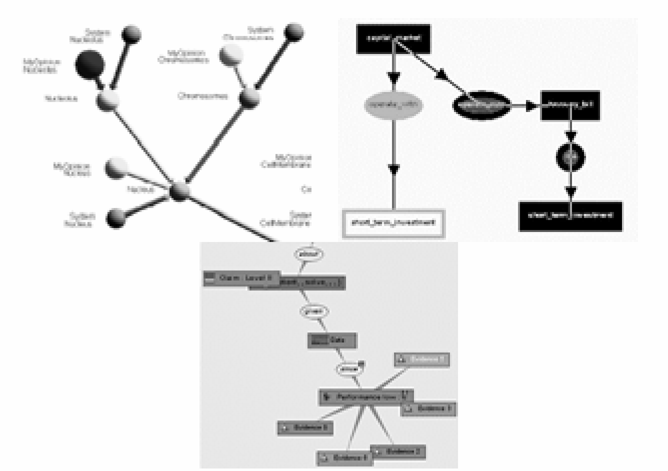

Fig. 15.7 Other structured open learner model presentations (. Zapata-Riviera and Greer 2004; VanLabeke et al. 2007; Dimitrova 2003)

Fig. 15.8 Textual learner model presentation in SIV (Kay and Lum 2005)

users able to select their preferred views without difficulty (Mabbott and Bull 2006)); or multiple views with different aspects of the model information (e.g. VanLabeke et al. 2007)). Furthermore, the presentation method of the learner model may be adapted to the individual (Mazzola and Mazza 2009). Both user choice of view to access, and adaptive model presentations, are feasible – the most appropriate likely depending on the context of use.

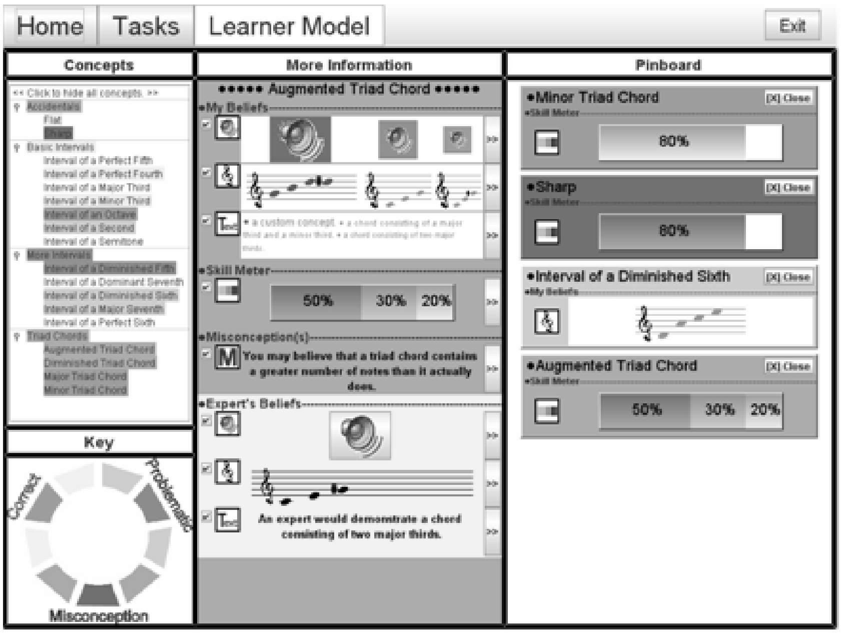

Fig. 15.9 Non-traditional open learner model presentation I: music notation and audio (extended from Johnson and Bull 2009)

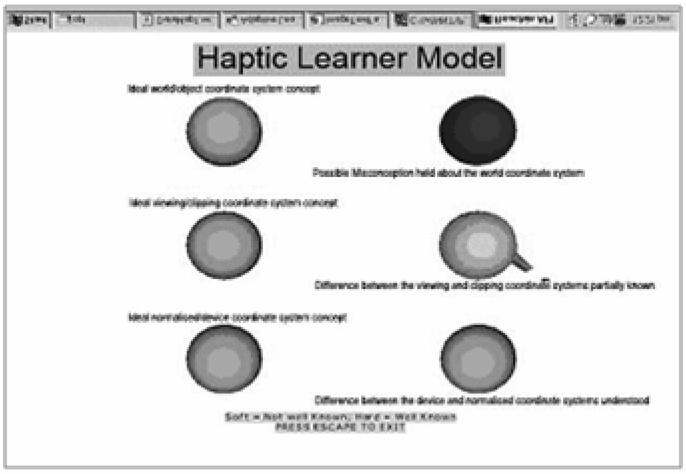

Fig. 15.10 Non-traditional open learner model presentation II: haptic learner model feedback (Lloyd and Bull 2006)

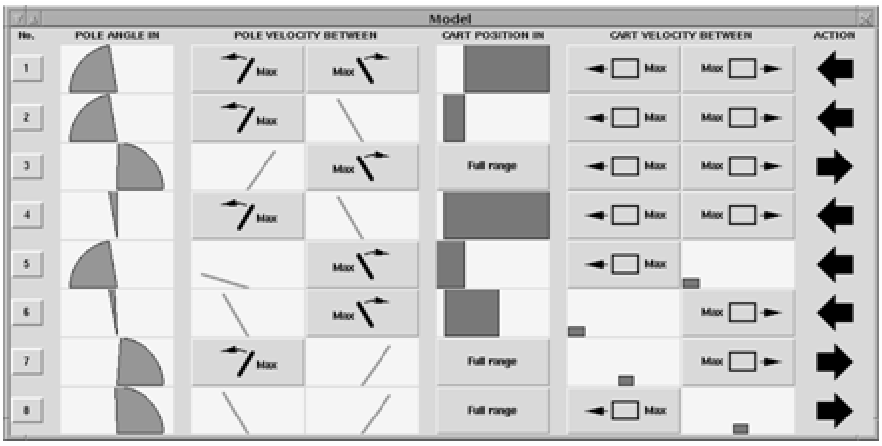

Fig. 15.11 Non-traditional open learner model presentation III: simulation task (operation of pole and cart device) (Morales et al. 2001))

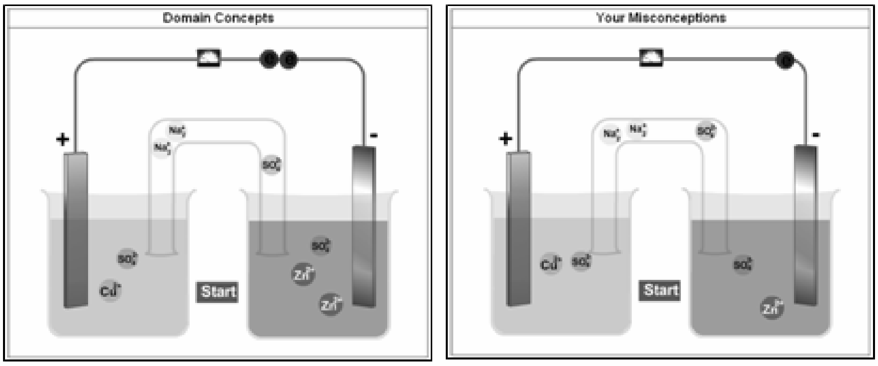

Fig. 15.12 Non-traditional open learner model presentation IV: animating learner beliefs (extended from Johan and Bull 2009)

15.3 Learner/System Control

As well as different methods of presentation of open learner models, the type of interaction a learner may have with their model and the level of control they have over the model contents, may differ. The question of learner/system control in open learner modelling is closely related to issues of metacognition in this context (Bull and Kay 2008).

15.3.1 System Control over the Learner Model Contents

The most straightforward form of open learner model is where the model is available for user viewing, but with no additional interactivity possible. These are known as *inspectable* learner models, and are completely under the control of the system - i.e. although the learner may view (or inspect) their learner model, they cannot make or suggest any changes to the system inferences about their understanding (or other attributes modelled). Most open learner models are in this category, including many of those introduced above. Inspectable learner models address the requirements for people to be allowed access to electronic data about themselves; but they also have the function of raising learner awareness of their knowledge, and prompting reflection, planning and formative assessment. Inspectable learner models are likely also to influence user trust in a system by confronting users directly with the system's inferences about their understanding.

15.3.2 Learner Control over the Learner Model Contents

In contrast to the above, *editable* learner models are learner models that are available for user viewing (as are inspectable models), but where the learner is able to change, or edit the contents. This is illustrated in Figure 15.13 by Flexi-OLM (Mabbott and Bull 2006). While the system may offer evidence or information to demonstrate where it disagrees with the learner's viewpoint (as is the case in Flexi-OLM, which can provide evidence in the form of the learner's responses to recent questions), the learner can in all instances override this if they wish, and so ensure that their desired changes to the model are effected.

Other examples help the learner to understand why and how the model was adapted to them, as illustrated in Figure 15.14 by SASY-unix, where the right-hand panel summarises the reasons for adaptation (e.g. "you want to get more than a pass grade", "you know the unix file system but haven't passed the quiz") (Czarkowski et al. 2005). Users of any SASY-based system can click the *why?* to see the reasons that the system believes this part of the learner model has its current value. They can inform the system of their own assessment of this part of the model. They can see if this will directly alter the value, as is the case for the belief "*you want to get more than a pass grade"*. Or, if they cannot alter it directly, as in the case of "*you know the unix file system but haven't passed the quiz*", they can see that doing the quiz could change the value. The upper right of the display shows how the page was adapted; in this case, 2 items were removed and 5 added, because of the current learner model components listed. The learner can click this to see just how the presented content was personalised, which parts added or omitted. Each of these presents details of the parts of the learner model that controlled that personalisation.

Therefore the learner can scrutinise the personalisation to see what has been personalised. They can also see the precise parts of the learner model that caused this, as well as the reasons that the learner model has its current value.

Similar to learner model editing is an approach where the learner may *challenge* their model, and justify the changes they make to the model. The system will still accept the user's changes (and therefore the learner can still be said to be editing their model), but this additional information from the learner can feed back into the learner modelling process (VanLabeke et al. 2007).

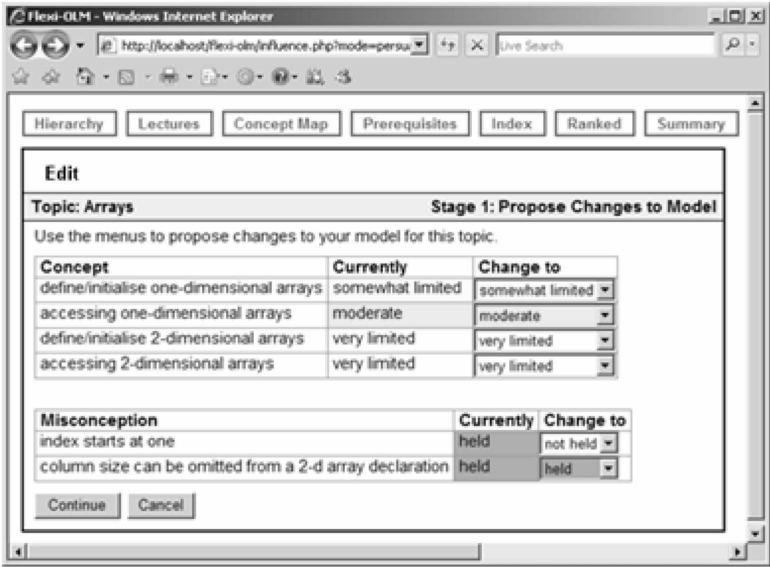

Fig. 15.13 Editing the Learner Model in Flexi-OLM (Mabbott and Bull 2006)

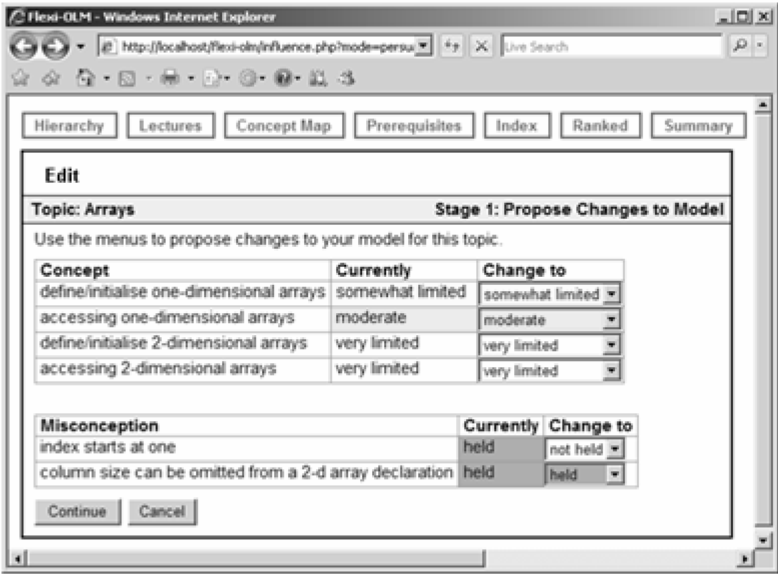

Fig. 15.14 Explaining the Learner Model in SASY-unix (Czarkowski et al. 2005)

Reasons for allowing learners to edit their model include enabling them to inform the system directly if: (i) their knowledge has increased (e.g. after a lecture or their own reading); (ii) they have forgotten information or techniques (to allow the system to consider or recommend appropriate revision); (iii) they were guessing (to allow the system to revaluate the learner model contents accordingly). Editable learner models place the learner in full control, inviting them to take responsibility for their learning interactions. The fact that a learner will need to be sure of any permanent changes they make to their learner model should also lead to them considering the options carefully, and so promote metacognitive activities as is the case with inspectable models. It may also increase user trust in a system as the user can control the data that determines adaptations in the interaction, if they wish.

15.3.3 Mixed Control over the Learner Model Contents

Interactive open learner models that allow an intermediate level of learner control include *co-operative* models (Beck et al. 1997), where the user and system provide different and complementary information for the learner model; *persuasion*, where the learner aims to change the model data (as in editable models), but the system will only subsequently alter the model if the learner can demonstrate that their self-assessment is accurate (e.g. by an additional short test) (Mabbott and Bull 2006); where additional information is provided for the learner model, to be considered alongside system inferences - i.e. the user may *add evidence* (Cimolino et al. 2004); and a truly balanced distribution of control of the learner model contents between the user and the system, where a negotiation process aims to achieve an agreed learner model. If this is not possible, any conflicts between the learner's and the system's representations are maintained in the model. This is illustrated in Figure 15.15 with Mr Collins (in the domain of pronoun placement in European Portuguese) (Bull and Pain 1995).

Negotiation can be undertaken in a variety of ways, for example: by menu selection (Bull and Pain 1995); dialogue games (Dimitrova 2003); and chatbots (Kerly and Bull 2008). Whatever technique is used, the key point is that the system and the user have equal rights to initiate and end discussions in negotiated learner models; and have the same negotiation moves available (e.g. offer information, request information, confirm, accept, critique, challenge, refute, justify).

Intermediate levels of interactivity in learner model maintenance may also require users to think carefully about any evidence they wish to add or remove, or discuss with the system. Therefore opening the learner model has a strong reflective element at various levels/types of interaction. While the learner is not able to edit the model to increase its accuracy, they do have the opportunity to directly influence the contents (though any proposed changes may not be agreed by the system). This increased involvement in the modeling processes may also affect user trust. Indeed, it has been suggested that learners may have greater trust in an environment where there is mixed control over the learner model, than full user control (Ahmad and Bull 2008). The most appropriate approach will likely depend on the context in which the open learner model is to be used.

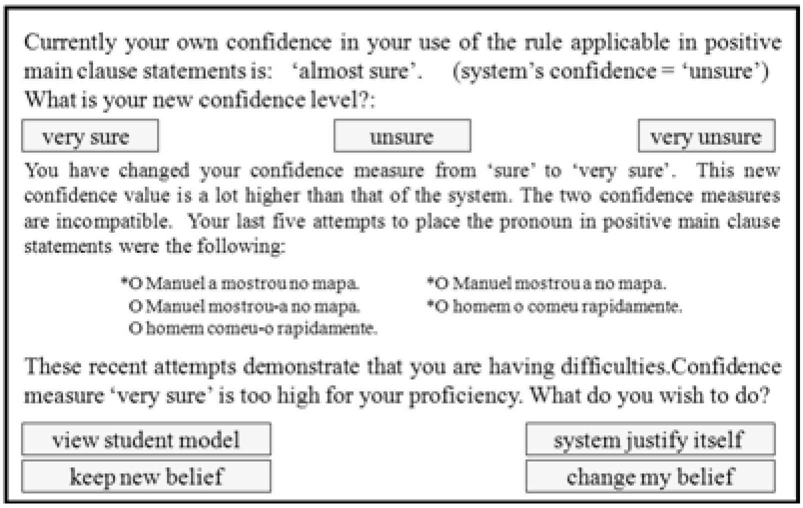

Fig. 15.15 Negotiating the Learner Model in Mr Collins (Bull and Pain 1995)

15.3.4 Independent Open Learner Models

Open learner models are usually integrated into an adaptive learning environment for consultation by the learner during their personalised interaction. This takes various forms, but well-known examples include skill meters for display alongside problem-solving and other tutorial support in an intelligent tutoring system (Mitrovic and Martin 2007) and in adaptive educational hypermedia providing navigation support (Weber and Brusilovsky 2001).

Whereas traditionally, adaptive learning environments (including those with open learner models) often have greater control over an interaction, independent open learner models (Bull and Mabbott 2008) are *independent* of a larger tutoring system. The learner model is constructed as in any system, but there is no additional (or only limited) tutoring or system guidance based on the learner model. The control and responsibility for decisions in their learning rest entirely with the learner: their planning and activity choices are facilitated by the contents of their learner model (we are therefore not concerned in this sub-section with control over the learner model contents, though the above distinctions are also applicable in independent open learner models). Although most open learner models are part of a larger system, independent open learner models have been successfully trialled in a variety of contexts (e.g. with trainee pilots (Gakhal and Bull 2008), language learners (Shahrour and Bull 2008), university students (Bull and Mabbott 2008) and schoolchildren (Kerly and Bull 2008)). Figures 15.2 (OLMlets) and 15.5 (Flexi-OLM) show examples of independent open learner models.

15.4 Open Learner Models for Other Users

Open learner models are applicable not only to individual learning scenarios, but can also be used in group learning. This may include individual models released by the learner to other group members – i.e. instructors or peers will see the specific information that the learner releases to them, as in OLMlets (Bull and Britland 2007) (Fig. 15.16). This enables learners to find collaborators (e.g. to seek help or to jointly work on an area where both individuals have weak knowledge; to compete with others; or simply to compare their progress against that of other users while preferring to work alone). Individuals may also be able to compare their own knowledge of a topic or concept (indicated by a star) on a five-point scale of very low to very high, to the knowledge of the group. Instructors can benefit from information about the progress of the group they are teaching, or

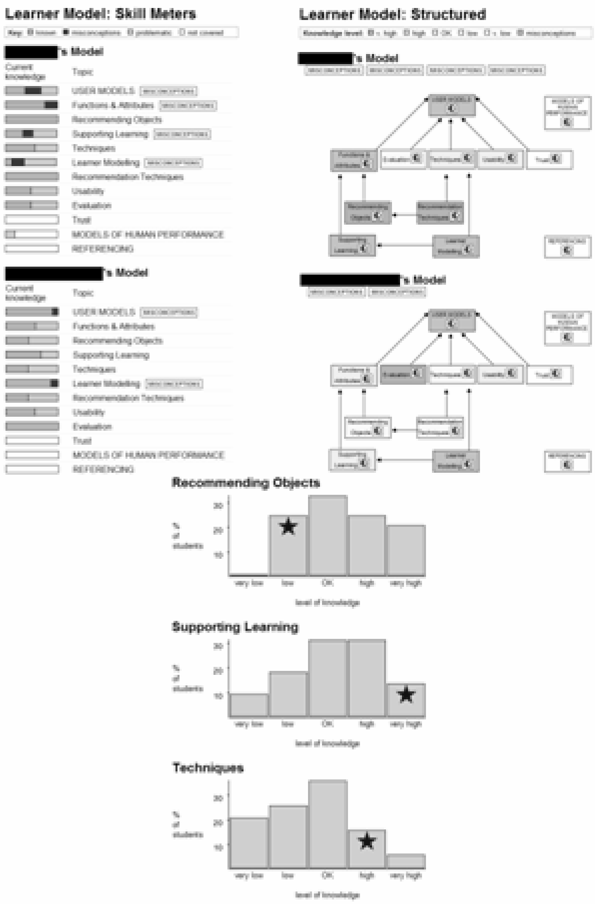

Fig. 15.16 Individual learner models accessible to other users (student names hidden in this image), and group model in OLMlets (Ahmad and Bull 2009; Bull and Britland 2007)

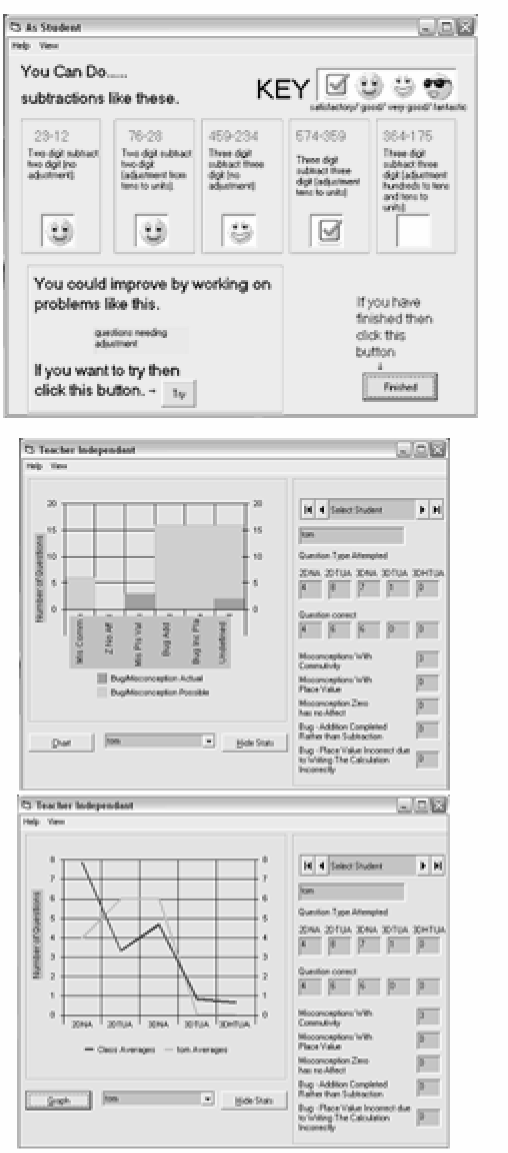

Fig. 15.17 An open learner model for children (upper) and teachers (lower) in Subtraction Master (Bull and McKay 2004)

from information about an individual's specific knowledge (or misconceptions). The learner model can be accessed in the format of choice of the viewer of the model (i.e. the same views are available to all users, but a peer or instructor who has been given access to an individual's learner model may select how to view it).

Fig. 15.18 An open learner model for children (left) and additional information for parents (right) in Fraction Helper (Lee and Bull 2008)

Similar approaches also allow the teacher to access information about an individual or groups of students, for example, using concept map, table, bar chart and text presentations for individuals or groups (Perez-Marin et al. 2007b). Systems may use different model presentation formats for different categories of user. For example, in DynMap (Rueda et al. 2003), the student may view the concept map of their current beliefs in a simpler format than does the teacher, who can follow more detailed representations of the evolution of the student's knowledge. In Subtraction Master (Bull and McKay 2004), the child views their learner model as a series of simple smiley faces representing the extent of their subtraction skills at different levels of difficulty. The teacher has more detailed information available, to help them to help a child individually. (This includes not only misconceptions identified, but also cases where misconceptions could have been demonstrated but were not, based on the subtraction questions that the child attempted.) This is illustrated in Figure 15.17. Similarly, as shown in Figure 15.18, Fraction Helper (Lee and Bull 2008) provides additional information to parents, over the learner

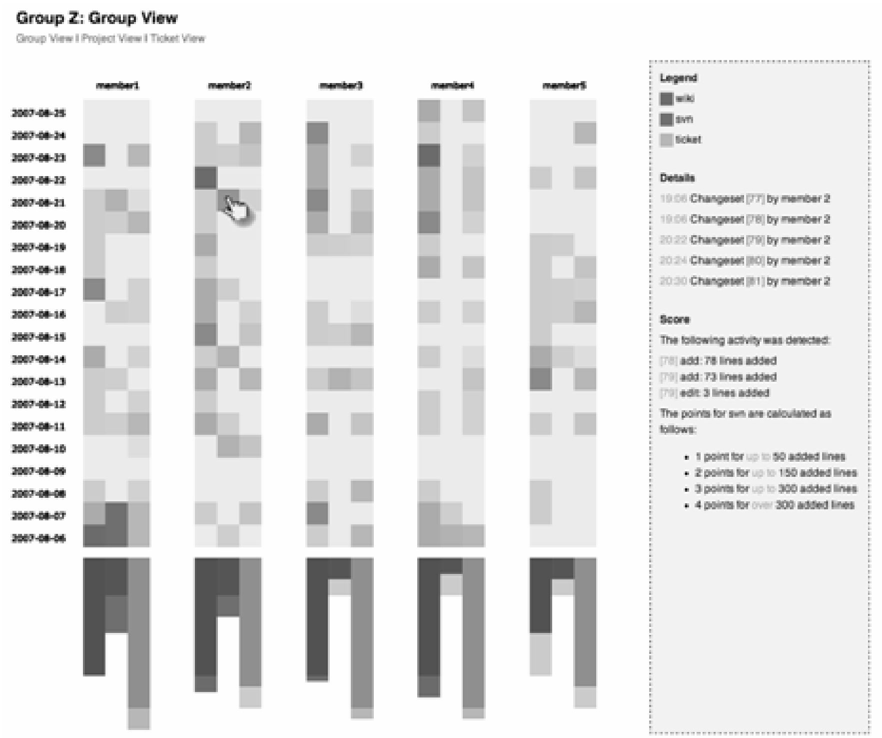

Fig. 15.19 Group activity model in Narcissus (Upton and Kay 2009)

model representations seen by their child. Nevertheless, the information for parents is still quite simple, as it is not assumed that all parents will have sufficiently advanced skills to interpret complex information. (Adapting the learner model presentation for parents is an issue that may benefit from further research.)

Other open learner models that permit instructor (and sometimes other user) access include REPro (Eyssautier-Bavay et al. 2009), CosyQTI (Lazarinis et al. 2007), CourseVis (Mazza and Dimitrova 2004), INSPIRE (Papanikolaou et al. 2008), Logic-ITA (Yacef 2005), MIM (Zapata-Riviera et al. 2007), PDinamet (Gaudioso et al. 2009).

Open learner models may also reflect group learning. A simple example was shown in Figure 15.16, but group open learner models can have much greater complexity. For instance, supporting long term group work based on evidence from group work tools, with the aim of facilitating effective group functioning. Figure 15.19 shows individual contributions to the group over time (each column represents one group member, with the brightness of a square showing the level of activity at that time) (Upton and Kay 2009) but as it uses very simple measures, it also links directly to the evidence and allows the learner to control the system decisions about when to make a square brighter. Evaluations of this and an earlier version (Kay et al. 2007) indicates that it helped team members identify group work problems and negotiate solutions.

It was also used by the group facilitator (tutor) to help with group problems and it served as a way to navigate the information space, a new role for an open learner model.

15.5 Summary

This chapter has provided an overview of some of the central issues in open learner modelling, with a particular focus on the ways in which open learner models are presented to the user; differences in user/system control over the learner model data and their learning; and learner models that are accessible to other users (e.g. peers, instructors, parents). While there are now many systems containing open learner models, there remain a range of directions for research in this area, including those areas presented in the introduction (from the SMILI open learner modelling framework (Bull and Kay 2007)), but new areas will likely also emerge.

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