

Supporting Learning with Open Learner Models

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SUMMARY

This paper describes a survey undertaken to discover students' wishes concerning the contents, interaction and form of open learner models in intelligent learning environments. It was found that, in general, students are receptive to the idea of using open learner models to support their learning. Several different kinds of open learner model are presented, which illustrate a range of approaches and issues relating to the use of open learner models.

KEYWORDS: *open learner models, intelligent learning environments.*

INTRODUCTION

An intelligent learning environment (ILE) adapts the educational interaction to the specific needs of the individual learner, according to information it holds about that student in a learner model. The learner model is a model of the knowledge, difficulties and misconceptions of the individual. As a student learns the target material, the data in the learner model about their understanding is updated to reflect their current beliefs. Thus the system can continue to adapt the interaction as appropriate for the student, as they learn.

Learner models are not usually accessible to the students they model. However, some work has investigated the educational benefits of allowing students to access their learner model contents. It has been argued that the act of viewing representations of their understanding can raise learners' awareness of their developing knowledge, difficulties and the learning process, which should, in turn, lead to enhanced learning (e.g. Bull & Pain, 1995; Dimitrova et al, 2001; Kay, 1997; Mitrovic & Martin, 2002). Thus opening the learner model to the student can offer them a useful additional learning resource.

This paper introduces an investigation undertaken amongst university students, to discover their potential interest in open learner models to support their learning. It then presents a variety of open learner models designed to help promote learner reflection.

DO STUDENTS WANT OPEN LEARNER MODELS?

Kay (1997) suggests a variety of reasons for opening the learner model to the learner, to help them to identify: what they know; how well they know it; what they want to know; and how to learn it. This section presents the results of a survey on whether university students would want to have access to their learner models. Subjects were 19 students taking a third year course called 'Interactive Learning Environments' and 25 MSc students taking a course in 'Educational Technology', a total of 44 students. Students were administered an anonymous questionnaire

following a lecture on intelligent learning environments, which included examples and discussion of open learner models. They had also been directed towards papers on open learner models, and web-based ILEs with open learner models (though it is not known to what extent students had consulted these). The aim was to investigate students' likely acceptance of the approach of making the learner model accessible. A positive result will enable us to develop systems with open learner models in a manner that may be of interest to students, as it has sometimes been found that students may not view their learner model when it is available (Barnard & Sandberg, 1996; Kay, 1995). Taking student wishes into account in the design of open learner models may help to overcome this problem. However, whether students will actually use different open learner model environments in practice, remains to be seen. The students in this investigation had an interest in educational technology, and may therefore be more open to the idea of accessible learner models than the average student. Their results may not transfer easily to another target population. This survey is therefore only a very first step.

Reasons for an Open Learner Model	Yes	Maybe	No
Right to view data about oneself*	31	8	4
Navigation aid	34	10	0
Planning learning	29	14	1
Reflection on learning	35	9	0
Improve user modelling	28	16	0

* One student did not answer this question

Table 1: Reasons for wanting access to the learner model

Table 1 shows that while some students were unsure in each of the categories, most students believe it is their right to view their learner model, and want access for this reason (70%). The majority would like to use their learner model as a navigation aid (77%), to help them plan (66%) and reflect on their learning (80%), and to contribute to the learner modelling process (i.e. help to improve the accuracy of the model - 64%).

Type of Open Learner Model	Yes	Maybe	No
Inspectable	17	19	8
Co-operative	20	19	5
Editable	22	14	8
Negotiated	15	21	8
System-initiated learner model presentation / interaction	24	15	5
Learner-initiated learner model presentation / interaction	13	19	12
Mixed-initiative learner model presentation / interaction	16	21	7

Table 2: Preferred type of open learner model

There are four main types of open learner model: inspectable (for viewing only); co-operative (where modelling tasks are shared between student and system, according to the ease with which each can perform the particular modelling tasks); editable (the student can alter the contents of the learner model at will); negotiated (the student and system discuss the model contents and come to an agreed representation). While there is a stronger preference for co-operative (45%) and editable models (50%), Table 2 suggests that there are sufficient students interested in each of the approaches to make further investigation of each type of open learner model worthwhile in a practical environment. Indeed, between 32% and 48% were undecided whether they would use one of the approaches. In practice some of these might find the open learner model useful. Even

if not all students access their learner model when it is available, we can still provide this facility for those who find it beneficial. Over half would prefer the system to initiate model viewing (55%). However, a large minority would also like to initiate inspection or interaction with the learner model themselves (30%), or would like there to be mixed-initiative learner model presentation or interaction (36%). 34%-48% were unsure of their preference for initiation of model viewing.

Contents and Presentation of the Open Learner Model	Yes	Maybe	No
Statement of known topics / concepts	37	6	1
Statement of problematic topics / concepts	40	4	0
Statement of misconceptions	37	6	1
Overview of understanding only	8	8	28
Details of understanding only	14	9	21
Overview and details of understanding	26	16	2
Preference for graphical presentation	35	8	1
Preference for textual presentation	10	27	7
Preference for both graphical and textual presentation	32	9	3

Table 3: Preferred contents and presentation of the open learner model

Table 3 shows the data students would like to have accessible in their open learner model. Most would like access to details of their beliefs: knowledge (84%), difficulties (91%) and misconceptions (84%). Many students would prefer both an overview and details to be available (59%). However, some students would be content with one or the other. It therefore seems important to consider offering learners the choice of overview or details, or the possibility of accessing both, if the level of detail of the learner model presentation is not predetermined by the teaching philosophy of the system or the purpose of rendering the learner model accessible. Most students want either a graphical (80%) or mixed graphics and text learner model (73%), while a smaller amount would be happy with a text only presentation (23%, with 61% unsure).

Comparing the Open Learner Model	Yes	Maybe	No
Comparison of learner model to domain model	25	17	2
Comparison of learner model to required material	28	8	7
Comparison of learner model to models of peers	24	14	6

Table 4: Preferred objects of comparison to the learner model contents

Table 4 suggests that over half of students want to compare their learner model contents to the expert domain knowledge (57%), to the expectations for the course (e.g. what they need to know to pass - 64%), and to the learner models of peers (55%). Relatively few were specifically against any of these options.

Access to the Open Learner Model	Yes	Maybe	No
Anonymous learner model open to other students	24	17	3
Identified learner model open to other students	6	13	25
Learner model open to others as part of aggregate model	25	15	4
Anonymous learner model open to instructor	36	7	1
Identified learner model open to instructor	19	17	8
Learner model open to instructor as part of aggregate model	33	8	3

Table 5: Preferences for opening the learner model to others

Table 5 shows that students are in general quite keen for their anonymous learner model to be available to their instructor, either as an individual model (82%), or contributing to an 'average' model for the group (75%). 43% would also be happy for their learner model to be available if it was identified as theirs (with 39% unsure). 18% would not want their instructor to see a model that could be identified as theirs. 55% of students would be happy for their individual model to be available to peers in anonymous form, and 57% would willingly release it as part of an 'average' group model. In each case, over a third of students were unsure. However, few were happy for their learner model to be available in named form (14%). 57% were clearly against this. Few students were strongly against any of the other options.

This section has presented students' perceptions about their likely acceptance of a variety of features of open learner models. Of course, this does not tell us about their use of systems with open learner models in practice, but it will help us to consider potentially important issues at the design stage. Use of open learner models will then need to be evaluated in an authentic learning setting. The following section presents a variety of open learner models addressing some of the issues presented above.

OPEN LEARNER MODELS: SOME EXAMPLES

The underlying learner model representations in a system may be simple or complex. Simple models that indicate only a learner's level of knowledge of a range of topics can, of course, only present this simple information back to the learner. More complex models can make more detailed information available to the learner through an open learner model, though the existence of a complex model does not necessarily mean that the learner will have admission to all the model contents - they may have access to only a higher-level overview. Open learner models can be used with a range of modelling techniques, e.g. Bayesian networks (Zapata-Rivera & Greer, 2001); knowledge tracing in cognitive modelling (Corbett & Bhatnagar, 1997); constraint-based modelling (Mitrovic & Martin, 2002). Most of the systems introduced below model learner knowledge as a subset of expert knowledge, problematic areas (or lack of knowledge), and misconceptions, and make this information available to the learner (as suggested important to learners in Table 3). The focus of this section is the presentation of, and interaction with the open learner models, rather than the underlying learner modelling techniques.

Simple Presentations of Open Learner Models

A simple presentation of open learner models will display a student's level of achievement in a series of topics or concepts. An example is OSMS (Open Student Model System) in Figure 1. A student's knowledge is shown as a subset of expert knowledge (a part-filled star). In addition to this overview, OSMS displays a statement of the student's knowledge (lower left) and difficulties (lower right), as suggested in Table 3.

Simple presentation of open learner models is more commonly in the form of skill meters (e.g. Corbett & Bhatnagar, 1997; ELM Research Group, 1998; Linton & Schaefer, 2000) which, as in the OSMS example, indicate the extent to which students have mastered material. Figure 2 gives a typical example from the AstroLearn system. With skill meters it is not usually possible to distinguish whether, for example, a learner has attempted 40% of a topic with 100% accuracy, in which case they are doing well; or whether they have attempted more, but are experiencing some problems and only have 40% correct. The focus is on achievement, as it is suggested that it is better to concentrate on knowledge than difficulties (Linton & Schaefer, 2000). However, as Table 3 indicates, students may well find information about their problems to be useful.

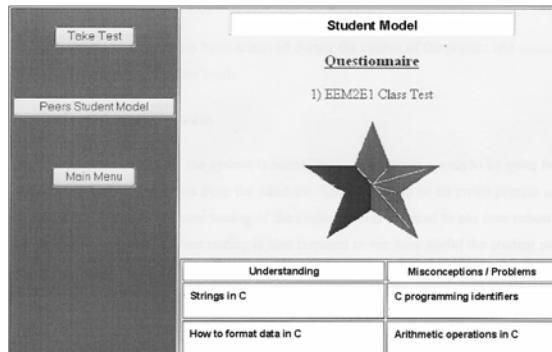


Figure 1: Simple graphical representation of progress with statements of understanding, problematic topics and topics with misconceptions

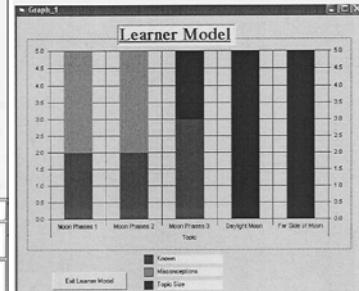


Figure 2: A simple skill meter

Mitrovic & Martin (2002) extended the skill meter representation to display a student's knowledge as a subset of material covered which, in turn, is a subset of the topic. This addresses the above problem to some extent, as the problematic or misconception area is made explicit. Nevertheless, it remains unclear whether this area represents difficulties in knowledge acquisition or misconceptions. Figure 3 shows C-POLMILE's (Bull & McEvoy, 2003) solution to the above limitations of skill meters. Here, as with other skill meters, we see the proportion of material known. However, the area representing additional material covered is a different colour, depending on whether the concepts are not yet learnt (but have been attempted), or whether the learner has some misconception. The fact that misconceptions are illustrated separately from other problematic areas aims to raise learner awareness of the existence of misconceptions. This distinction could also help learners to better direct their efforts to where the need is greatest. Table 1 suggests that both support for reflection and an aid to planning are desirable features of open learner models.



Figure 3: C-POLMILE's skill meter, illustrating knowledge level, areas of difficulty, misconceptions and size of the domain

A further difference between the skill meter of C-POLMILE and other skill meters is that the size of topics and concepts is indicated by the length of the skill meter (usually skill meters are all the same length, as in the example in Figure 2). This should help learners to appreciate the amount of work required to master each topic (again, an aid to planning, as suggested by Table 1). The skill meters are shown in conjunction with numerical values representing the proportion

of known and covered topics, to more easily enable direct comparisons between the level of understanding or progress of different topics, because such comparisons are more difficult when the length of the skill meter is varied to illustrate the size of the topic. Likely misconceptions are listed, to draw a student's attention to them, in accordance with the findings of Table 3.

Simple learner model presentations are required for young children, as they may not readily comprehend complex representations of their understanding. Figure 4 shows an open learner model for 8-9 year olds, which uses a series of different smiling faces to represent satisfactory, good, very good and excellent progress.

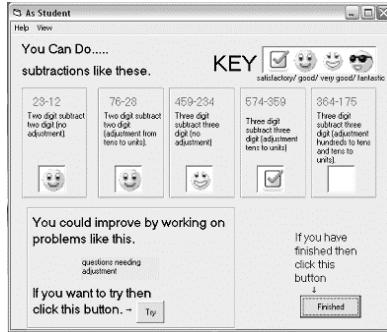


Figure 4: The Subtraction Master open learner model for children

It was found that children with a range of abilities could understand the meaning of their open learner model (Bull & McKay, to appear). Zapata-Rivera and Greer (2002) also achieved positive results with slightly older children. Further work on the use of open learner models for children therefore seems warranted, to complement the more common investigations with adults.

Haptic Learner Model Feedback

The visual feedback of TOLM (Tactile Open Learner Model) in Figure 5 is straightforward, as in the examples in the previous section. Concepts of which the learner has some understanding are depicted as green spheres (left), and misconceptions as red spheres (right).

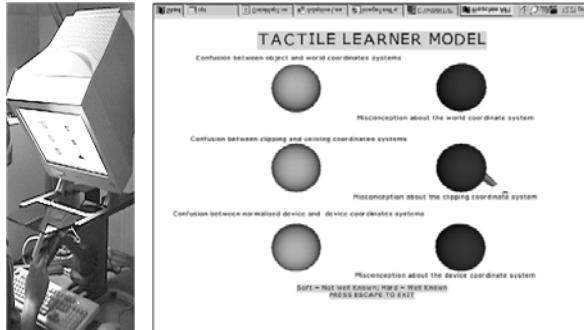


Figure 5: A haptic learner model

The spheres are 3D tactile objects. Additional haptic feedback is provided using the SensAble Technologies PHANTOM (www.sensable.com), combined with the Reachin Display unit (<http://www.reachin.se>) - set-up shown on the left of Figure 5. In the learner model, concepts that are known well feel hard, while concepts that are less well known feel softer (green spheres). The degree of softness varies according to the extent to which a learner understands the concept represented. Magnetism is used to indicate misconceptions - i.e. as the learner moves towards the concept, if they hold a misconception (red sphere), the object draws them towards itself because of its magnetism. Thus misconceptions feel soft and sticky. The strength of the magnetism varies according to the severity of the misconception. The haptic feedback therefore provides additional information to the visual feedback.

Viewing Other Learner Model Attributes

It is, of course, not only data relating to knowledge that can be held in a learner model. Figure 6 shows a simple learner model representation of a student's learning style. Learners can select between different presentations of, and interactions with the same domain content. The more times they successfully use a particular presentation and interaction method, the stronger the evidence becomes for the likely utility of the approach for that individual, indicated by the figures for the four methods in the left hand panel. A graphical indication is given in the lower screen area, where coloured circles are drawn towards the button for the recommended approach. This information about preferred interaction style is not only for use with the system, but is also intended to help raise learner awareness of their approaches to learning more generally.

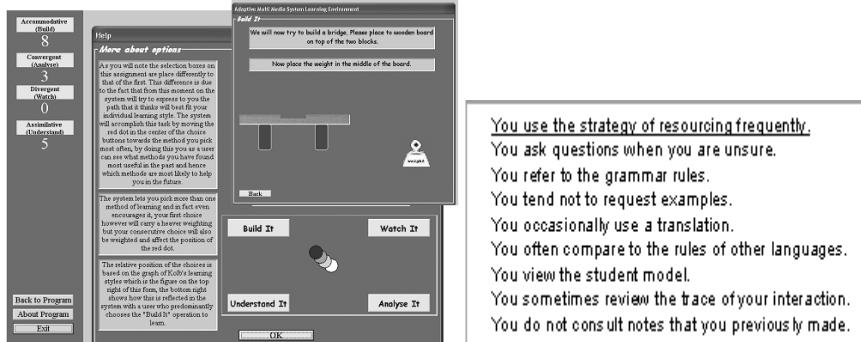


Figure 6: Showing the learner's learning style

Figure 7: Showing the learner's learning strategies

Mr Collins models information about a student's use of learning strategies while using the system (Bull, 1997), based on O'Malley and Chamot's (1990) language learning strategy classification. Figure 7 illustrates a learner's use of the resourcing strategy. This kind of information should not only make explicit the strategies the learner is observed to be using, but also enhance their knowledge of other learning strategies that they might find useful.

Alternative Presentations of Open Learner Models

As in the above examples, most systems with an open learner model always display the model in the same way. However, as suggested in Table 3, it has been shown that learners may like to access their learner model in different formats (Mabbott & Bull, to appear). JPLE (Japanese Particle Learning Environment) is a simple example of a system that offers alternative

presentations of the learner model data (Bull & Nghiem, 2002). This can be in the form of a table showing correct versus incorrect attempts at using different particles, and an overall weighting of competence based on performance. The competence level for the use of particles can also be displayed graphically. The two forms of the open learner model are shown in Figure 8. Learners can access both representations together, as illustrated, or can choose the one they prefer.



Figure 8: Alternative presentations of the learner model (I)

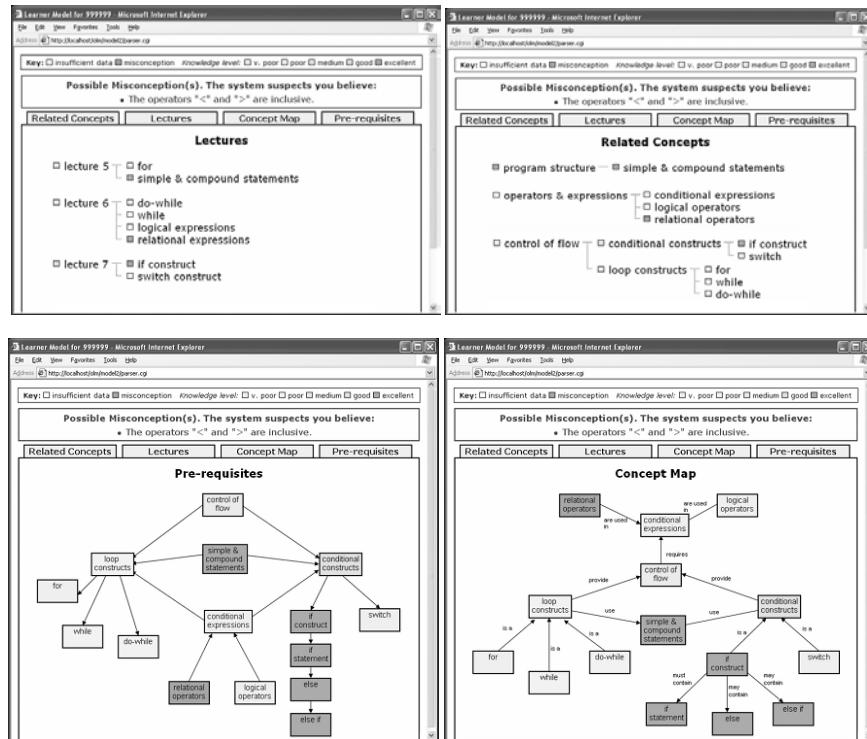


Figure 9: Alternative presentations of the learner model (II)

Figure 9 also shows different views on the same learner model data (Mabbott & Bull, to appear). The first presents an overview of the learner model data following the lecture structure, the second uses related concepts, the third uses a pre-requisites structure, and the fourth, a concept map. Coloured nodes indicate the extent of knowledge of each concept. It was found that there was no single preferred view, but that individuals did indeed have preferences for which view(s) they wished to use. Work is currently ongoing to include additional learner model presentation formats. Misconceptions are listed separately in each view, to provide the more detailed information on problems, as indicated as potentially important in Table 3.

Negotiated Learner Models

The previous examples were concerned with presenting the learner model to students for viewing. Negotiated learner models allow the student and system to jointly discuss and agree on the contents of the learner model. This has the dual purpose of achieving a more accurate learner model (as the learner can sometimes contribute information that is harder for a system to infer); and promoting learner reflection (as students must justify any changes they try to effect in their learner model). Both purposes are indicated to be important in Table 1. A negotiated model implies a symmetrical relationship between the system and student in the maintenance of the model - i.e. either can initiate the negotiation process, and each participant has ultimate control over their own representations in the learner model. Thus sometimes the model may hold inconsistent beliefs if the student and system cannot agree on the contents. The negotiated approach may be especially suitable for those learners who would prefer a learner model interaction that could be initiated by either the learner or the system, but also for those who would prefer only the system to initiate negotiation (as students can avoid initiating learner model interaction themselves). According to Table 2, this is likely to be the majority of learners of the type surveyed. However, a negotiated learner model is probably less suitable for the 30% who would like to initiate the interaction themselves, as they would not be able to stop the system questioning them about their learner model if it disagreed with them.

Figure 10 shows part of an exchange between learner and system in Mr Collins (Bull & Pain, 1995), where the student is attempting to increase the strength of the system's representation of their knowledge. The first part of Figure 10 shows the overview of the model, contrasting the student's view of their knowledge with the system's representations. The second part shows the negotiation process. The student is attempting to change a learner model representation to a level that the system disagrees with. The system challenges the student, offering a number of alternatives. The student asks the system to justify its argument, so the system provides evidence. The system will continue to offer alternative options if the student wishes to continue negotiation. If the student convinces the system that their view of their knowledge is correct (for example, if they prove that they understand the rule by answering a test question), the system will update the model as the student wishes. However, if the system cannot be convinced (i.e. the student offers insufficient evidence), the system will maintain its current belief.

The pronoun is:	YOUR CONFIDENCE (a - d)	SYSTEM CONFIDENCE (1 - 4)
Pre-verbal in negatives e.g. <i>Não os compra</i>	unsure (c)	very sure (1)
Post-verbal in positive main clauses e.g. <i>Compra-os</i>	almost sure (b)	unsure (3)

Figure 10: Negotiating the learner model

Open Learner Models for Handheld Computers

Recently there has been much interest in the potential for mobile learning. For mobile intelligent learning environments, some of the important issues relating to learner modelling may differ from those in the desktop PC context (see Bull et al., 2004). Where learning environments span both the desktop PC and a mobile device, it may be important for the learner to be able to update the learner model between sessions. For example, the C-POLMILE system introduced above, can be used on both a desktop PC and a handheld computer. The learner model is transferred between devices during synchronisation, in order that the student will always receive an appropriately adapted interaction. However, there may be occasions when a learner has not synchronised devices between sessions. In such cases they will need to be able to easily update their learner model to reflect their current understanding. Table 1 shows that many students would be happy to contribute to improving their learner model, with no students responding negatively. The C-POLMILE learner model is therefore directly editable by the learner. Table 2 suggests this may be welcomed by around half of users, with others unsure, and less than one fifth being against editing their model. The desktop version of C-POLMILE was illustrated in Figure 3 above. Figure 11 shows the learner model screens for the handheld computer.

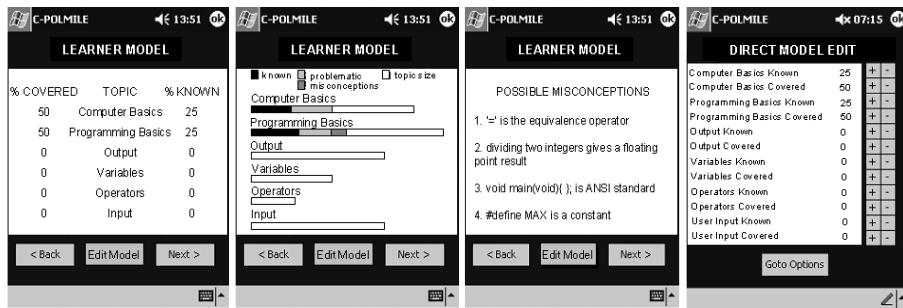


Figure 11: C-POLMILE's mobile open learner model

As shown in the screen for the desktop version of the open learner model, the handheld version also gives a numerical overview and skill meters indicating knowledge, problematic areas, misconceptions and size of topic. Also shown in Figure 11 (right) is the mechanism for altering the representation of knowledge level for each topic. Misconceptions can be deleted from the model if they no longer apply, by clicking on them.

Figure 12 also illustrates the learner model of a system that spans the desktop PC and handheld computer. However, in contrast to C-POLMILE, the MoReMaths (Mobile Revision for Maths) interactions are different on each device (Bull & Reid, 2004). The main interaction takes place on the desktop PC, where a learner is more likely to have time and be able to concentrate on the interaction. At the end of the session the learner synchronises with their handheld device. Individualised revision materials are created, according to the contents of their learner model. The learner model is also synchronised for viewing. The handheld information is intended for use when the learner is on the move, or has short periods of time for study, away from the desktop environment. Thus they can make use of time when they would not normally be able to undertake individualised study. A graphical overview of performance is presented, with textual presentation of details from the learner model. This accords with the results of Table 3.

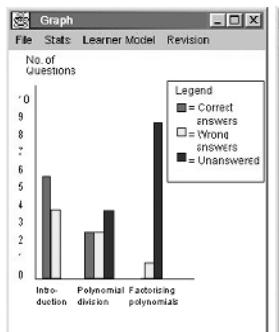


Figure 12: The mobile open learner model of MoReMaths

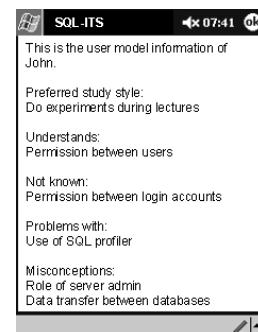
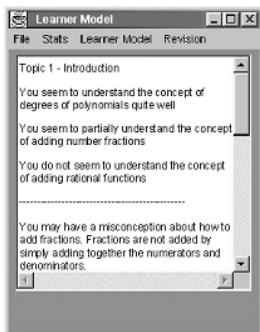


Figure 13: A shared mobile open learner model

In a pen and paper study, Bull and Broady (1997) found that spontaneous peer tutoring can occur if co-present students are shown the contents of their respective learner models. With the increase in use of mobile devices, it is possible for learners to routinely carry around their learner models. When they come into contact with other students from their course, either for planned study sessions or opportunistically, they can exchange learner models and help each other out. Figure 13 shows the very simple learner model presentation of SQL-ITS, designed for this purpose. The simplicity of the model is intended to easily show the differences in understanding of the various topics when comparing learner models, and prompt learners to think about the subject themselves. Learner models such as in MoReMaths could also be used for this purpose. Ongoing work is investigating the effect of presenting pairs (or groups) of learners with more detailed learner model information, combined with specific suggestions for peer tutoring.

Opening the Learner Model to Others

Continuing the theme of widening learner model access to other users, as in the above example, Kay (1997) suggests that learners may wish to compare their progress to that of their peers. Table

4 also suggests that students might find this useful. However, few systems have investigated the use of peer models. An example is described by Linton and Schaefer (2000), who display a learner's knowledge against the combined knowledge of other user groups, using a skill meter.

Subtraction Master, described above, allows children to compare their performance against that of the 'average model' of children in their class. It was found that, as proposed for adult learners, some 8-9 year old children are interested in viewing peer models (Bull & McKay, to appear). The Subtraction Master average peer model is illustrated in Figure 14, showing a child's progress as compared to the progress of others in their class.



Figure 14: The Subtraction Master average peer model

JPLE, also introduced above, allows users to view the learner models of other individuals to compare them to their own learner model, as perceived useful by over half of students in Table 4. Comparison of learner models may be achieved using either of the learner model views, as illustrated in Figure 15.

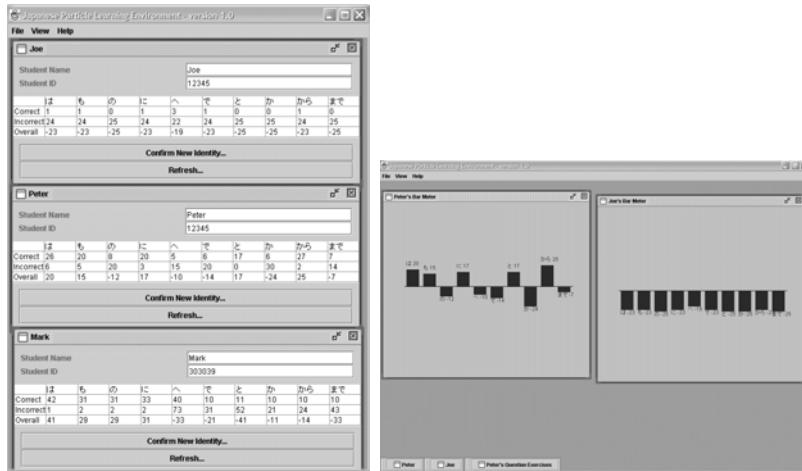


Figure 15: Viewing the learner model of peers

Peers can also be involved in the process of learner modelling. PeerISM (Bull et al., 1999) allows pairs of students to contribute to the learner model contents of each other by providing

qualitative and quantitative peer feedback on assignments. The system then combines the quantitative feedback with its own inferences about the performance of both participants, to update the learner models of each student. This is illustrated in Figure 16. A student's self assessment (column 1) is shown alongside the human peer assessment (column 2) and the assessment of an artificial peer (column 3). The overall model is shown in the final column, which attempts to reconcile any inconsistencies between the other models.

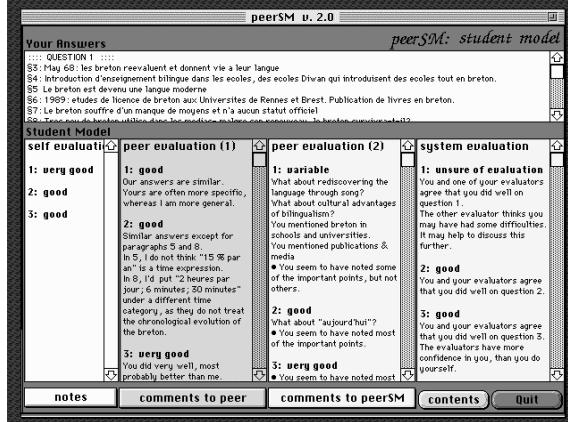


Figure 16: Contributing to the learner model of peers

Another set of users who may be given access to learner models, are instructors - i.e. tutors can access the representations of the progress or understanding of those they teach. The instructor may use their students' learner models as a source of information to help them adapt their teaching to the individual learner, or to the group (e.g. Zapata-Rivera & Greer, 2001). Table 5 suggests many learners may be happy for their learner model to be available to their instructor.

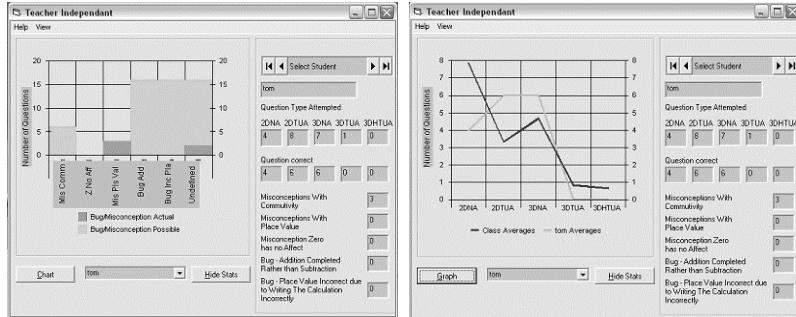


Figure 17: An open learner model for teachers

Subtraction Master (described above) not only opens the learner model to the child, and generates an average model for the group, but also provides access to teachers, to the learner model of individuals and the group as a whole. The form differs as the presentation format for 8-9 year old children is necessarily simple. Teachers can see areas in which a student could have exhibited misconceptions given the questions attempted (shaded light) in Figure 17, and the

misconceptions that were actually observed (shaded dark). The last column shows 'undefined' errors. The right hand side of the screen shows a child's performance across the question types and the strength of evidence for the various types of misconception or bug. Teachers can edit the model of an individual to reflect changes in their knowledge - for example, if the teacher had been coaching the child at the computer, resulting in the child now understanding their problem, the teacher could edit the learner model to update it. The second screen shows the teacher's view of an individual's performance against the average achievement of the group. (The group data can also be presented without comparison to a specific individual.)

SUMMARY AND CONCLUSIONS

This paper has investigated students' requirements for open learner models, suggesting that many students are receptive of the idea of using open learner models. However, we do not yet know much about students' use of such models in practice, as few large scale studies have been conducted. Students' expectations will not always remain the same when confronted with a real example. Nevertheless, their views give us a starting point for the design of systems with open learner models, which can then be evaluated in practice. Of the studies that have been undertaken, it has been suggested that some students may indeed benefit from viewing their learner model (Mitrovic & Martin, 2002), whereas other work has found that often students do not consult their learner model when it is available (Kay, 1995). The participants in the survey described in this paper were all computer-literate and, moreover, were interested in educational technology. These are, of course, legitimate subjects, as they may indeed use intelligent learning environments with open learner models. However, if designing such systems for other students, the requirements may differ as the views of our subjects may not generalise to a wider group.

The second part of the paper introduced a variety of implemented open learner models, as an illustration of the range of issues that can be considered for open learner modelling systems, and to suggest directions for future research.

ACKNOWLEDGEMENTS

Thanks to: Paul Brna (Mr Collins, PeerISM), Lisa Ko (AstroLearn), Tim Lloyd (TOLM), Andrew Mabbott (alternative presentations), Adam McEvoy (C-POLMILE), Mark McKay (Subtraction Master), Adam Moskovich (learning style), Theson Nghiem (JPLE), Harpreet Pabla (OSMS), Helen Pain (Mr Collins), Eileen Reid (MoReMaths), Wei Yang (SQL-ITS).

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