Supporting Interaction Preferences and Recognition of Misconceptions with Independent Open Learner Models

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Abstract. Misconceptions have been identified in many subjects. However, there has been less investigation into students' interest in their misconceptions. This paper presents two independent open learner models used alongside seven university courses to highlight the state of their knowledge to the learner as a starting point for their independent study. Many students used the environments; many had misconceptions identified at some point during their learning; and most of those with misconceptions viewed the statements of their misconceptions. Students were able to use the independent open learner models in a variety of ways to suit their interaction preferences, at different levels of study.

1 Introduction

There is much interest in misconceptions, with research in various subjects: materials engineering [1]; chemistry [2]; astronomy [3]; statistical reasoning [4]; special relativity [5]; electrical circuits [6]; java [7]; cardiovascular phenomena [8]. Given the prevalence of misconceptions, a method of helping students recognise such problems would be useful. We introduce two independent open learner models (OLM) to support preferred ways of interacting, to help students identify difficulties in order that they may undertake appropriate independent work according to this information.

Jameson defines a user-adaptive system as "an interactive system which adapts its behaviour to individual users on the basis of processes of user model acquisition and application which involve some form of learning, inference, or decision-making" [9]. A *learner model* is typically inferred based on the user's responses to questions or attempts at problem solving. This relates to the model acquisition part of Jameson's definition. The learner model is compared by the system to its expert model to predict appropriate tutoring or guidance actions for the user according to their learning needs, for example: individualised feedback or explanations; revision material or suitable new material; relevant link adaptations; tasks and exercises on an appropriate topic at an appropriate level. This relates to model application in Jameson's definition.

Usually the learner model is not accessible to the user. An *open learner model* is a learner model that the user can access. An advantage of OLMs is that they can help raise awareness of knowledge, prompting metacognitive activities such as reflection, self-evaluation and planning (see [10]). Presentation of the model can be in a variety

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of forms, from high level overviews such as skill meters [11], [12]; to OLMs incorporating information about conceptual relationships [13], [14].

In *independent open learner models* the model is constructed in the usual way (inferred from user input). However, rather than providing user guidance in line with their inferred needs, responsibility for decisions in learning remains with the learner. Independent OLMs help students identify their learning requirements in order to undertake appropriate work, often outside the system. The independent OLM is therefore a means of encouraging learner independence and responsibility for learning. Adaptation based on "user model acquisition and application" [9] is thus different for independent OLMs. Model application usually relates to inferences based on the model (e.g. for adaptive tutoring as described above). In an independent OLM, model application primarily refers to externalising the model contents. The user then decides appropriate application of the model information to further their learning. The traditional roles of adapting presentation or navigation support in adaptive hypermedia [15] also differs in focus when independent OLMs are employed: adaptive presentation relates to the display of model information (e.g. presentations of descriptions of misconceptions held); adaptive navigation support can be an automatic outcome of displaying the learner model. (Of course, further adaptations may also be made, e.g. misconception descriptions that take account of knowledge of prerequisite concepts required to understand certain statements.)

While some adaptive learning environments adapt or recommend based on learning or cognitive style, it has been suggested that matching an interaction to style is not necessarily effective [16], [17]. Therefore our OLMs allow the user to interact as suits them (accessing the OLM in their preferred format; extensive/limited use; consulting materials during/after an interaction; returning/not returning to check new knowledge). Survey results suggest that students would be interested in obtaining information about their misconceptions from an OLM [18]. In this paper we consider the extent to which students will consult descriptions of their misconceptions in practice in an independent OLM, as a starting point for independent study; interacting in a manner that suits their preferred approaches to learning.

2 Independent Open Learner Models: OLMlets and Flexi-OLM

Our first system, OLMlets, is subject-independent: it can be used in any course for which appropriate multiple choice questions can be created. Instructors input questions and define misconceptions. The OLMlets learner model is inferred based on the most recent five attempts at a topic, with current knowledge level and misconceptions represented in the underlying model by a number between 0 and 1. Use of simple modelling techniques allows easy deployment in a range of courses, as OLMlets does not require instructors to define detailed relationships between concepts. Simple modelling necessarily results in simple model presentations.

The most common simple OLM is the skill meter. OLMlets also uses this format, as in Figure 1 (left). Medium shading (green) in the first, second and last topics of the skill meters shows level of knowledge. The dark shaded (red) portion of the skill meter in the first and last topics indicates the extent to which the learner holds misconceptions. Misconception descriptions are viewed by clicking on the 'misconceptions' link.

Lighter shading (grey) shows more general difficulties (not linked to specific misconceptions). White means that insufficient questions have been attempted to model user understanding. There are four additional views of the model, to accommodate learner preferences. Figure 1 also shows the graph view. Similar to the skill meters, the graph represents knowledge level by the proportion of the area of a meter that is green; with red and grey also used in the same way as in the skill meter view. The main difference between these views is that in the graph, the positive information is on one side of an axis, and the negative information is on the other. A text view is also available, giving a text statement of knowledge level. A table view shows knowledge level in ranked order. Boxes portray knowledge level by the colour of a box surrounding the topic name, using one box for each topic. Learners can use this information in a variety of ways, for example: to plan their study; to navigate to relevant materials (M icon); to select areas on which to answer further questions (Q icon).

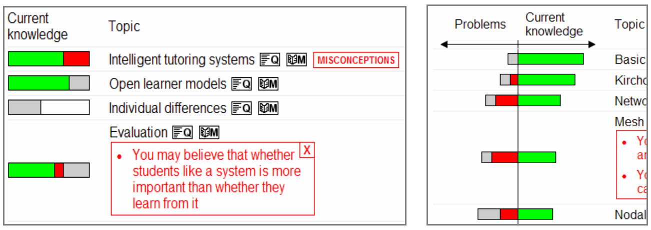

Fig. 1. Excerpts from the OLMlets skill meter and graph views

The misconception statements are based on common difficulties identified from diagnostic tests, tutorials, lab exercises, coursework and examinations. Misconception examples from our courses include the following, with the misconception statement (italics) seen by the student (prefixed by "you may believe that...").

- *Voltages are summed at a node (1st year Circuit Analysis)*
  In nodal analysis of circuits, currents at nodes are summed in accordance with Kirchoff's current law, and the resulting simultaneous equation solved to find the currents in the various branches of the circuit. In mesh analysis, drops in voltage around each branch are summed according to Kirchoff's voltage law. The misconception arises from confusion between the two methods of circuit analysis.
- *The fundamental frequency of a square wave is 1/T (1st year Info. Engineering)*
  Students may remember an equation from previous studies, giving frequency as the reciprocal of period. Thus they may associate 1/T with the fundamental frequency. However, in this context T is only half the period of the waveform, because one period is made up of a positive going pulse of duration T and a negative going pulse of duration T. So the actual period is 2T and the fundamental frequency is 1/(2T). The misconception is likely to be held by students who try to remember formulae rather than working from sketches or mental images.
- *A control group that does nothing is an ideal comparison for evaluating learning gains (3rd year Interactive Learning Environments)*

> Students sometimes believe that measuring learning gains resulting from some feature of an interactive learning environment should be achieved by comparing to a control group that had no instructional intervention. This often seems to be based on an assumption that a control group 'controls' by doing nothing (any learning gains are therefore due to the learning environment). However, this does not allow for effects such as time on task or multiple variables in the experimental condition.

Our second system, Flexi-OLM, uses multiple choice and short answer questions for C programming. As with OLMlets, Flexi-OLM models users over the last five attempts and represents knowledge by a number between 0 and 1, but because it was designed for a specific subject, the modelling is at a more fine-grained level in terms of the breakdown of topics and concepts - therefore allowing more detailed OLM views. Figure 2 shows excerpts from the lecture hierarchy/tree and concept map. The colour of nodes indicates knowledge level, with further breakdown of concepts and statements of misconceptions available from the links. In total there are 7 views, the other 5 being: related concepts (tree), prerequisites (map), alphabetical index (list), ranked (list), statement of knowledge level (text). Misconceptions include the following (prefixed by "you may believe that", when seen by students):

- *The '=' operator is used for comparison (1st year C programming)*
  Equality testing is performed with the '==' operator (e.g. if(x == y)...). Because the '=' operator is used for assignment (i.e. when setting the value of a variable), some students assume the same operator is used to test for equality. Further confusion arises because some programming languages *do* use '=' for this purpose.

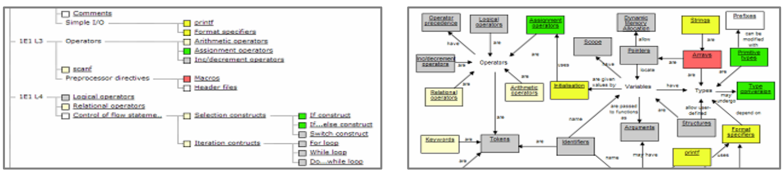

Fig. 2. Excerpts from the Flexi-OLM lecture structure and concept map views

3 Student Use of Independent Open Learner Models

In this section we focus on six OLMlets courses selected to illustrate use of OLMlets in introductory (1st year) and advanced (3rd year) modules; and use of Flexi-OLM in an introductory (1st year) C Programming course, to allow comparison of simple and more complex OLMs at the same educational level.

The OLMs aim to help learners recognise their needs in order to make more informed decisions about their learning. We therefore do not attempt to measure learning gains, since a low level of knowledge in the learner model might relate to a user who successfully identified their difficulties when viewing their OLM, and worked to overcome them away from the system. Not all users will feel a need to return to check their new knowledge. It is assumed students will use an independent OLM to the extent that they benefit, which may differ for different students. This study therefore complements work demonstrating learning with OLMs (e.g. [11],[19]). We investigate whether students will consult descriptions of their misconceptions at introductory and advanced levels, using simple and complex OLMs. We also investigate the range of study approaches that can be supported by an independent OLM.

3.1 Participants, Materials and Methods

Participants were 276 students taking courses in the Electronic, Electrical and Computer Engineering department at the University of Birmingham. 211 students were using OLMlets in 6 modules (1st year – Circuit Analysis; Semiconductors; Information Engineering; Mathematics; 3rd year – Computer Hardware and Digital Design; Interactive Learning Environments). 3rd years were experienced OLMlets users, having used it previously in other courses. We focus on courses at these levels in which lecturers had defined a range of misconceptions. 65 students were using Flexi-OLM (1st year C Programming). The above figures exclude the few students who logged in and then attempted only a small number of questions.

The OLMs were offered alongside the courses throughout a term in the case of OLMlets, and 2 terms in the case of Flexi-OLM. The learner models were assessed in the Semiconductors and Interactive Learning Environments modules; use was optional in the other modules. The logs and learner models were examined to reveal usage patterns and misconceptions, and questionnaires were used to obtain user comments (we here use the open-ended comments). Student data was anonymised.

3.2 Results

In order to place OLMlets usage patterns of our 6 modules in context, we first consider the extent of use of OLMlets in all 14 courses in which it was deployed in the 2006-2007 academic year. A mean of 66% (median 64%) of students taking the 14 courses used OLMlets. This ranged from around one sixth of students in two modules, to all students in four modules. Table 1 shows usage for each course considered in this paper, measured by percentage of students using the systems. Table 1 also shows the percentage of users who held misconceptions at some point, and the percentage of those holding misconceptions, who viewed their misconception descriptions. Most of those with misconceptions had between 1 and 4, but some held as many as 8-10.

Table 1. Usage of OLMlets and Flexi-OLM

Year	*Course*	*OLMlets/Flexi-OLM users*	*Users with miscon.*	*Viewed miscon.*
1	C Programming	48% (F-O)	95%	83%
1	Circuit Analysis	94% (O)	97%	93%
1	Semiconductors	94% (O)	87%	73%
1	Information Engineering	65% (O)	88%	83%
1	Mathematics	120% (O)	94%	71%
3	Comp. Hardware & Digital Design	59% (O)	95%	87%
3	Interactive Learning Environments	100% (O)	100%	97%

The percentage of students using the OLMs differed for each course, ranging from almost one half, to over 100% (i.e. there were also students answering questions who were not actually registered to take the module). Students were attempting different numbers of questions, from around 20 to well over 1000. Across the courses 71% of users attempted over 50 questions, with 56% attempting more than 100 questions. In all courses, a large majority of users held misconceptions at some point during their learning. Most of these students viewed the descriptions of their misconceptions. Student comments further illustrate the utility of the misconception statements, and how students used the information about their misconceptions. For example:

- The misconceptions link was useful as it gave me a chance to see exactly what problems I faced.
- The way my misconceptions are highlighted encouraged me to resolve the misconceptions.
- The misconceptions feedback was useful - I went back to the notes and the books, revised the material and then got the questions right.
- I talked to my friends about our misconceptions and we helped each other.
- It helped talking to other students who had got further than me to overcome my misconceptions and problematic areas within the weaker topics.

Using one topic from a course in each case, Figures 3 and 4 illustrate the way in which students typically used OLMlets. There were no differences across courses or levels. Figure 3 gives an example of a student making extensive use, and Figure 4 an example for a student with lower use. The x axis shows the number of questions answered for that topic (in chronological sequence), with the peaks/highest levels showing correct responses; the middle levels, general problems (incorrect answers or selection of the unsure option); and the lowest level, misconceptions. There was no difference in the extent of use depending on the number of misconceptions held; though those with very strong knowledge identified at the start tended to use OLMlets less.

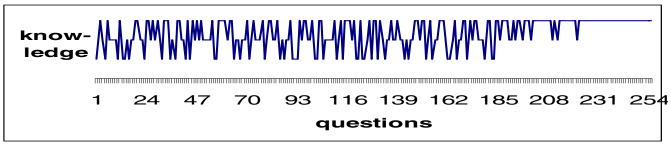

Fig. 3. Pattern of responses of an extensive user

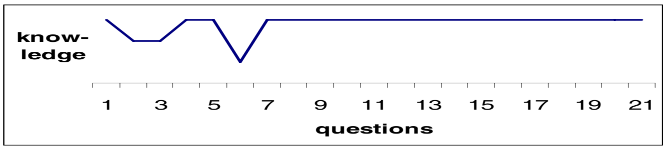

Fig. 4. Pattern of responses of a lower level user

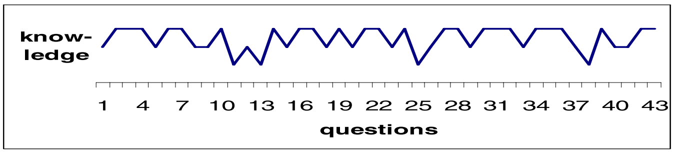

Fig. 5. Pattern of responses of a non-returning user

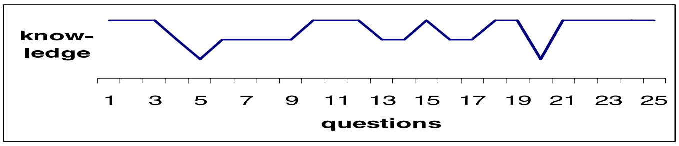

Fig. 6. Pattern of responses of a user being assessed (ceased using OLMlets)

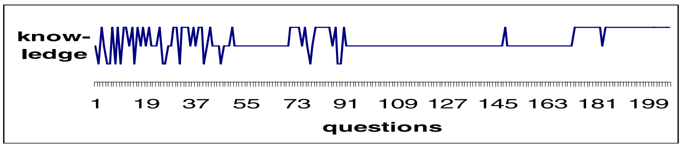

Fig. 7. Pattern of responses of a user examining questions as a learning strategy

Students often worked with OLMlets until they achieved a level of knowledge of which *they* were confident – i.e. they did not cease answering questions immediately upon achieving an 'excellent' model (indicated in Figures 3 and 4 by the fact that there are many points at which they could have stopped towards the end of the interaction, with excellent knowledge: a series of 5 questions indicating correct responses). The user in Figure 3 required many questions to eradicate their difficulties and specific misconceptions, and to become sufficiently confident in their knowledge; the user in Figure 4 achieved this with fewer questions. Others continued use beyond achieving an 'excellent' state, but to a lesser extent - often after a series of around 10 correct responses on a topic. Some students stopped using OLMlets when it still showed difficulties as illustrated in Figure 5, not returning to check their knowledge. Thus students appeared to use OLMlets in different ways, to suit their individual needs.

In the modules that assessed the model, some users stopped answering questions on a topic once they had achieved an 'excellent' representation, as in Figure 6 where, following a misconception (question 20) and previously fluctuating knowledge, the user answered 5 more questions correctly and then ceased interacting on the topic.

Sometimes students adopted a different strategy as shown in Figure 7 for an extensive user. We show here a learner who appears to start answering questions according to their understanding, but on determining their knowledge, switches to studying the questions and answering 'unsure' on most attempts. The learner eventually returns to answering questions according to their beliefs, demonstrating the disappearance of the earlier misconceptions.

The above examples show the most common usage patterns (with Figures 3, 4 and 5 showing very common patterns), which were found across all courses at both levels. A student tended to use a similar approach for each topic where they had similar levels of difficulty, with a lower level of use on topics for which they had good knowledge. (It should be remembered that the Figures show just one topic from a course – e.g. the student who answered 254 questions in Figure 3 attempted similar numbers of questions in the other topics.)

For consistency we have here used OLMlets usage patterns to illustrate students' interactions with an independent OLM. Use of Flexi-OLM was similar. For example, there were differences in the extent of use of Flexi-OLM, and whether students continued to use it until they achieved a good level of knowledge in the various areas. There were also many users who continued interacting on a topic beyond the point at which excellent knowledge had been demonstrated. Thus the complexity of the model display did not appear to affect usage patterns.

3.3 Discussion

Although there is no reason why students should necessarily use OLMlets or Flexi-OLM if they are already confident of their strengths and weaknesses, sufficient numbers were using the OLMs to suggest provision of this approach is worthwhile. Indeed, in some courses students were using OLMlets optionally at the same level as in courses where the learner models were assessed. As there were a greater number of OLMlets users in the mathematics module than were registered on the course, we hypothesise that the additional users had recognised a need to improve their mathematics skills in order to progress well in another course. The smaller percentage of Flexi-OLM users may be because it was used in one course, whereas OLMlets has more prominence in the department as it is deployed in several courses; or it may be due to the greater complexity of the OLM - some may have found Flexi-OLM harder to use. This issue warrants further investigation. Nevertheless, it appears that both simple and detailed independent OLMs can be found useful by many, and this may be applicable at different levels of learning or OLM familiarity as illustrated by the simpler system (OLMlets) used at both introductory and advanced levels.

Although there has been much interest in identifying misconceptions and their underlying causes, and how knowledge of common misconceptions may be used in teaching, there has been less research into students' interest in their misconceptions. We do not claim that showing a student their misconceptions will be sufficient for them to understand their problems: our aim is to assist users in identifying that they have certain difficulties to help them focus on these problems in their independent learning (we aim to facilitate formative assessment and encourage learner independence). Table 1 shows that many students had misconceptions during their learning. Although the number seems quite high, it should be noted that these figures refer to students who had misconceptions *at some stage*. Nearly all those holding misconceptions inspected the descriptions of their misconceptions, thereby gaining information about their understanding that would not normally be available. Student comments suggest that they perceived the misconceptions statements to be helpful, and they used them to facilitate their learning in a variety of ways - both in individual study and in collaboration with peers. Given the extent of misconceptions across subjects indicated in the literature, our results may have relevance to a variety of course types.

Both users who make extensive use of an independent OLM (Figure 3), and users who make lesser use (Figure 4), may continue beyond the point at which their models display excellent knowledge. This suggests that, even where the OLM had identified strong understanding, some were keen to continue until they themselves felt confident of their knowledge. Given that this pattern occurred with students who used the OLM different amounts, this may reflect different strategies. The extensive user may adopt an approach of learning through observing the occurrence of errors (a trial and error strategy), while the less frequent user may be consulting lecture notes once having pinpointed their problems, then returning to test their newly acquired knowledge. This is, of course, speculation. However, the key point is that an independent OLM was used optionally by students with different interaction strategies, suggesting the potential of independent OLMs to support students with different approaches to learning.

Figure 5 demonstrates a user who ceased answering questions without returning to OLMlets, although their OLM still showed difficulties. In this case, after identifying difficulties, the learner may have independently overcome them - not needing to return to OLMlets for confirmation. As stated above, unless an OLM is used to summatively assess students, there is no expectation that they should return to a topic if confident in their knowledge, and so interaction patterns such as Figure 5 are considered equally acceptable as those that demonstrate improvement (Figures 3 and 4).

In the modules that assessed the learner models, some students stopped using OLMlets at the point where it showed excellent knowledge (Figure 6). There may be a tradeoff, therefore, between summative assessment aiming to ensure use of a system intended primarily to support formative assessment, and the formal assessment leading some to restrict their use in order to achieve the maximum mark. However, those not taking full advantage of the benefits of formative assessment may also do the minimum in other forms of assessment and assessment preparation. This is therefore an issue to investigate further. Would these students use an OLM more appropriately if there were no associated summative assessment? Or would they perhaps use it less, as the external assessment pressure would not apply? This also raises the question of validity of the summative assessment - knowledge levels in the OLMs tend to fluctuate when unstable knowledge is represented. In OLMlets in particular, where topics are often broader, if students cease using it at a point when they think it shows the maximum knowledge levels they believe themselves able to achieve, it may be overestimating knowledge. However, this may not differ from other strategic approaches to assessment that students adopt, and so it may be a more general problem.

An interesting strategy was observed amongst some, where they initially answered questions according to their knowledge, then examined questions/response options by repeatedly selecting 'unsure'. Figure 7 demonstrates the success of this approach, with a learner initially having difficulties but after extensive interaction where no attempt was made to select the correct response, the learner then answered accurately, demonstrating the disappearance of their earlier problems.

The interaction examples used reflect the most common interaction strategies. However, as stated above, the important point is not that these particular strategies were more common (or, indeed, the relative frequencies of the interaction types), but that independent OLMs can support *different* approaches to independent study. This may account for the fact that many students were using the OLMs optionally (in only two OLMlets courses did the learner models form part of the assessment).

4 Summary

This paper has described use of two independent OLMs. There were sufficient levels of use to suggest that many students found the information about their knowledge to be helpful. Most users had misconceptions during their learning, and most viewed descriptions of their misconceptions. Independent OLMs were shown to be able to support students with different usage strategies. We therefore suggest that an independent OLM approach may be of benefit to students in promoting understanding of their conceptual knowledge, including their misconceptions, in order to help them focus their study. This appears to apply for many learners with both simple and more detailed learner model presentations, and at different levels of study.

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