Metacognition and Open Learner Models

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Abstract. This paper considers some of the similarities between the goals of supporting and encouraging metacognition in intelligent tutoring systems and learning in general, and the benefits of opening the learner model to the learner and to the teacher. We identify the purposes for an open learner model and provide examples of two important classes of open learner models: those within a particular teaching system and those that are first-class citizens with value independently of a teaching system. We conclude with a discussion of the links between metacognition and the many purposes of making a learner model open.

1 Introduction

Metacognition, while having been defined in many ways, with differing emphases and labels, is generally considered to involve higher-order thinking about cognition, relating to knowledge about cognition and regulation or monitoring of cognition (or control over learning processes) (see e.g. [1],[2],[3]). Much of the work refers back to Flavell's introduction of "metacognition and cognitive monitoring", presented through discussion of metacognitive knowledge (comprising knowledge of person, task and strategy variables), and metacognitive experiences [4]. The importance of enhancing metacognitive awareness in learners has often been argued (e.g. [2],[5]), including the use of computer-based metacognitive support such as for training general learning ability [6]; tutoring help-seeking strategies [7]; developing self-awareness through learning by teaching [8]; a reflection assistant for problem-solving [9]; and encouraging learners to develop greater awareness of cognitive and metacognitive learning strategies [10].

Although metacognition is often described as requiring conscious processing and application, it has also been suggested that some lower levels of consciousness in processing may still be metacognitive, for example through habitual regulatory behaviour [3]. It is this latter view that we adpot in this paper: we acknowledge both the benefits of explicit metacognitive instruction or support, and the potential to support metacognitive activity in a less explicit manner. We discuss these issues with reference to open learner models.

Open learner models (OLM) are learner models that are accessible, or 'open' to the learner they represent (see [11],[12] for recent overviews of open learner modelling). There are a variety of reasons that a learner model might be open to the user, key purposes include metacognitive concerns such as: promoting reflection by externalising representations of the learner's knowledge; encouraging self- and formative assessment; facilitating collaborative interaction; and supporting planning and monitoring of learning. In the following section we explore metacognition in relation to two types of open learner model: those embedded in a tutoring system, and those used independently of the larger tutoring environment.

2 Metacognition in Open Learner Modelling

The SMILI☺ (Student Models that Invite the Learner In) Open Learner Modelling Framework provides a method of supporting the definition or description, and analysis of OLMs, which can lead to easier comparison between systems using OLMs. It covers various purposes for opening the model, summarised in the framework as: improving learner model accuracy by allowing the learner to make contributions to their learner model; promoting learner reflection through confronting students with representations of their understanding; facilitating planning and/or monitoring of learning; facilitating collaboration or competition amongst learners; supporting navigation; the right of access to information stored about oneself; learner control over their learning; trust in the learner model content; and assessment [11]. Issues relevant to metacognition in open learner modelling may relate to many of the above. In this paper we focus in particular on the following: learner reflection on their knowledge; formative assessment; self-monitoring and planning; learner control over, and responsibility for their learning.

Most OLMs are embedded in an intelligent tutoring system (ITS), and so designing externalisation of the learner model requires decisions about integrating viewing of the model into the larger interaction. We provide examples of OLMs in ITSs in Section 2.1, with a focus on how the OLMs aim to support metacognition.

Independent OLMs are learner models in isolation of a full ITS [13]. Learner modelling occurs in the usual manner (e.g. from questioning, tasks, help or hints requested), but the purpose of the independent OLM is to help learners to recognise any problematic issues themselves, through inspection of their learner model, and then independently carry out appropriate work to overcome difficulties identified. This approach has links with the goals of enhancing metacognitive behaviours, with a focus on encouraging learner independence. We consider independent OLMs in Section 2.2.

2.1 Supporting Metacognition with Open Learner Models in Intelligent Tutoring Systems

Learner models are the core drivers of personalisation in an intelligent tutoring system. They may well be the defining component of an ITS, since there is such diversity in the other elements that may be needed for any particular tutoring system. Learner models can take many forms, depending particularly on the system's knowledge representation and reasoning approach for the domain knowledge and the teaching expertise. The dominant form of learner model is substantially based on an overlay of the domain expertise and this means that the ease with which a model may be made available and understandable to a learner depends upon the representation of the domain. When that domain expertise is large or complex, it may be very difficult to make it usefully open to the learner. A natural approach to this problem is to define a part of the learner model that summarises the key elements that are meaningful and helpful for a learner. One excellent example of this is in the SQL-tutor [14], a constraint-based tutor which makes use of a large number of constraints. A summary of the aspects that make sense from a student's perspective is illlustrated in Figure 1. A comprehensive evaluation of this approach for two tutors showed significant learning benefits, especially for weaker students; and positive attitudes to this high level progress indicator [15]. Notably, the open learner model assisted students in making better choices about problems they should tackle, a metacognitive skill for managing their learning. This form of open learner model has also been used in cognitive tutors [16].

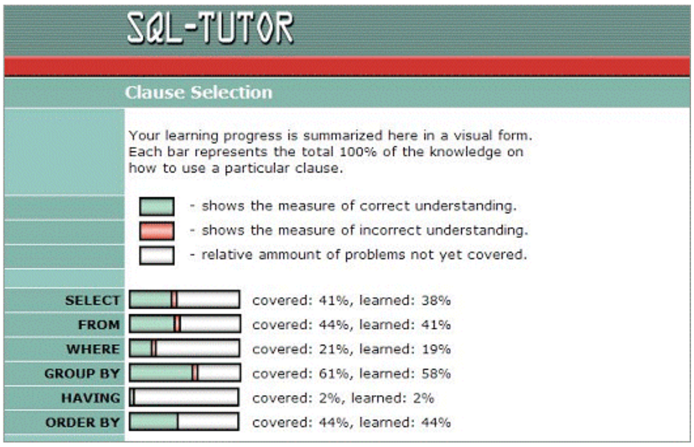

Fig. 1. Skill meters of the SQL-Tutor [15]

A similar role for a learner model, as a starting point for the student to decide what to learn next, is found in QuizGuide [17] (illustrated in Figure 2 by the targets and arrows). Although this is for the same broad domain, the underlying system representation is quite different, being based on a coding of each available task with the concepts or learning objectives. In both cases, the key issue is that the information made available to learners facilitates their ability to determine how well they are progressing in different aspects of the domain, providing a support for reflection. From this, the OLM facilitates learners' control of their learning as it helps them decide what to learn and how to plan their learning, important metacognitive skills. Indeed, these interfaces also help learners monitor their progress, because they can monitor the effectiveness of their plan, in terms of the changes in the open learner model.

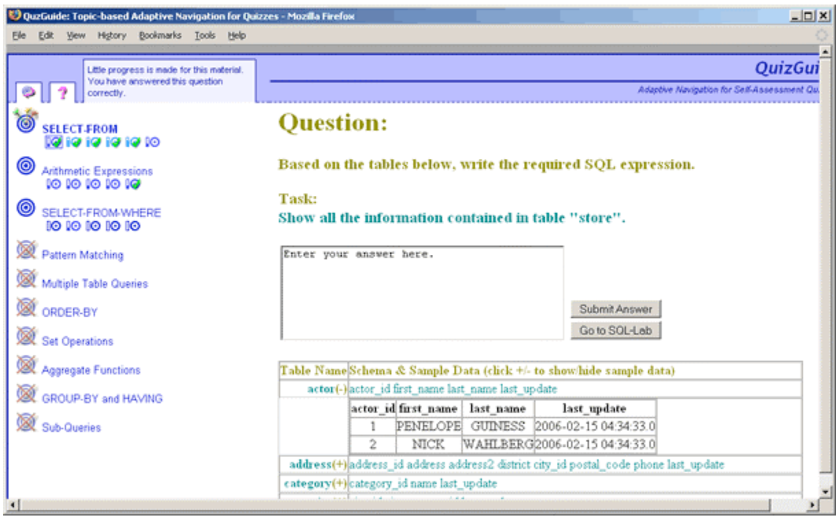

Fig. 2. Arrows in targets in QuizGuide [17]

A rather different approach to open learner modelling is illustrated in Simprac [18],[19], a tutor for management of chronic illness (Figure 3). Top left is one of the consultation interfaces, this example enabling the learner to examine parts of the simulated patient. The middle right screen shows the learner each of their actions in the last consultation, and they assess the importance of each question they asked the patient as well as each aspect of the examination and tests ordered. The lower histogram shows the learner's performance in terms of the issues they explored compared against their cohort.

One of the challenges of this domain is that learners can easily become entrenched in one perspective of the problem and its management: in spite of evidence that a management plan is ineffective, doctors may fail to recognise that this is the case. Accordingly, this whole tutor was created with a *reflective layer*, calling on the learner to reflect on all elements of the series of simulated consultations with patients. Following Schön [20], the tutor supports reflection *in-action*, *on-action* and *on-reflection*, all metacognitive actions. For the core goals of supporting metacognition, an important aspect of the design of the OLM is that it shows learners their own performance in relative terms at two levels. First, it shows their performance compared with the expectations of the author of the tutor, an approach that can ensure that the tutor fits in with the teaching approach of a course and programme. Second, it shows their performance compared with a relevant, matched group of learners. In Simprac, there are three groups: medical students, general practitioners and experts in the particular domain of the tutorial. This tutor deals with a very different class of task from the SQL of the systems above: notably, there is some disagreement between experts about the best practice. It may be unrealistic and discouraging to show a medical student their performance against an expert, especially as an expert may be able to use quite different strategies from those that are best for a medical student. There are open questions about how to design and present a learner model that can best support reflection and particularly how to do it in ways that facilitate learning of the domain and of metacognitive skills. However, one important issue involves ensuring that the learner can compare their own progress and performance against meaningful standards that fit into any broader learning context.

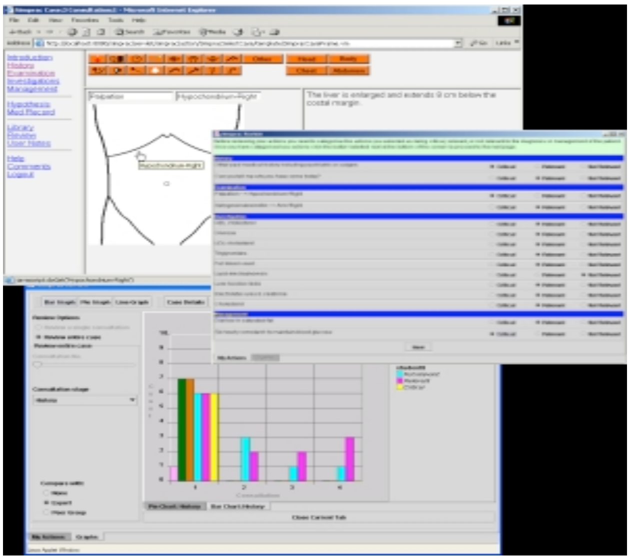

Fig. 3. Simprac OLM [18],[19]

While the above examples make available a quite small model, there may be cases where there is value in enabling a learner to gain an overview of a large model. This issue has been explored by in SIV [21]. The SIV visualisation enables a learner to see their progress over the hundreds of elements in a course in user interface design. The left part of the screen in Figure 4 shows the learner's knowledge of concepts by the size, colour and positioning of the concept labels. The ontology underlying SIV was critical for enabling learners to move up and down granularity levels and it also enables learners to focus sets of related concepts within the domain. Students used this to plan their study for final examinations, with the OLM showing areas where they had weakness. Notably, the evidence available for this OLM came from sources of varying reliability (shown to the user as illustrated in the right of the screen in Figure 4); and different learners interpreted that evidence differently, some valuing one source highly while other students did not. This raises the question of providing learners with control over the interpretation of evidence that informs their learner model: without this, the individual learner will find the OLM less useful. This raises some additional issues for metacognition and learner control, particularly whether the learner is entitled to decide how to value the different sources of learner modelling evidence.

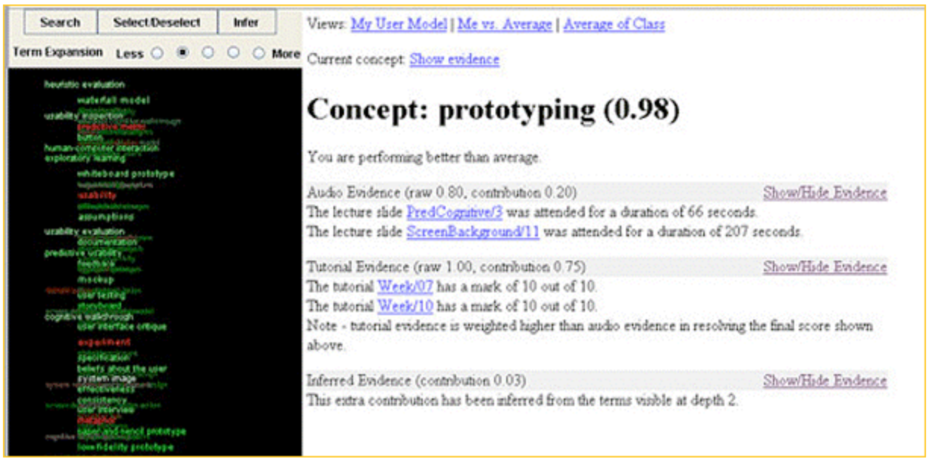

Fig. 4. The SIV overview [21]

SIV also provides a summary view of learning progress of the class, which was invaluable for the teacher. To this point, we have focused on metacognition in relation to the learner but any ITS or LMS or similar tool that is used in the context of a course, with lectures, labs and other activities, has the potential to support metacognitive skills of the teacher. A suitable OLM can enable the teacher to assess the effectiveness of their own teaching or a particular innovation: the OLM can show the progress of the class, and potentially this class compared with other relevant cohorts. Essentially, the teacher is a learner who is continuously learning how to teach. This metacognitive role for the OLM has broad significance. It has been shown to be effective in the context of a Logic Tutor [22]; and has been explored in the context of a widely used LMS: CourseVis showed a high level representation of a class activity on the LMS [23]. While the classroom teacher has a different relationship to an ITS than that of a student, there is potential for important learning gains if the teacher's metacognition is scaffolded by an OLM.

2.2 Independent Open Learner Models to Facilitate Metacognitive Activity

Unlike the examples in the previous section, we here consider OLMs that are designed for use independently of individualised teaching or guidance as is typically provided by an ITS. Such independent OLMs usually have, as their primary aim, the promotion of metacognitive activities such as self-assessment, self-monitoring, reflection and planning (as in some of the above examples), but within an overall context of encouraging autonomous or independent learning outside the system. Students use the OLMs to help them identify their knowledge and difficulties, and plan where they need to invest effort to overcome any problems. The responsibility for determining and undertaking appropriate activities lies with the learner.

Two independent OLMs displaying learner models at different levels of detail/structure, have demonstrated the possibility to support students alongside lecture courses - i.e. in real-use settings [13]. Figure 5 illustrates the simple skill meter and a similar graphical overview of knowledge level in OLMlets [24], and the structure of map and tree views of the Flexi-OLM learner model [25]. In each case, colour is used to represent the level of knowledge of a topic or concept, and short text statements of misconceptions can be viewed, designed to prompt learners into investigating their specific problems. For example, from OLMlets used in an Interactive Learning Environments course: "You may believe that whether students like a system is more important than whether they learn from it"; "You may believe that a system does not have to understand the learner model". From an introductory mathematics course: "You may believe that denominators are added when adding fractions"; "You may believe that, when adding matrices, the individual terms within a matrix are added together".

Fig. 5. Independent OLMs with simple displays (top: OLMlets [24]); and structured displays (bottom: Flexi-OLM [25])

OLMlets was designed specifically to promote formative assessment and learner autonomy for independent use alongside a range of courses [24], where learners answer questions relating to the key concepts of a course, and view a simple overview of their knowledge levels and statements of their misconceptions (top of Figure 5), as a starting point for their independent work. The simplicity of the model presentation reflects the simplicity of the underlying learner model, as it is intended for easy introduction by instructors, into a variety of courses. Deployment of OLMlets throughout several university electronic, electrical and computer engineering modules showed that students will use an OLM such as this to support their learning, and are able to do so in a manner that suits their learning preferences; and the structured tree and map views of Flexi-OLM (bottom of Figure 5), were also used by many students taking the C programming module for which it was designed [13]. As no additional tutoring or metacognitive support was provided in either case, any usage of the OLMs suggests that learners were gaining some benefit simply from the availability of an independent OLM. Thus, although we do not have specific information about how students were using these OLMs (e.g. to recognise their knowledge state, to plan their learning, to reflect on their difficulties?), the fact that they were using them suggests that some kind of metacognitive activity was taking place, that students perceived as beneficial.

Perhaps the clearest example of an independent OLM to prompt metacognition is the Notice OLM [26]. Notice is based on the second language acquisition literature on awareness and 'noticing' language features in language learning [27],[28], and 'noticing the gap' between one's own language rules and the (correct) target language forms [29]: issues that have much in common with the general metacognition literature. Notice uses salience/highlighting techniques (recommended for computer-assisted language learning (e.g. [30]), to draw the learner's attention to grammatical elements. Figure 6 shows the 'comparison view': coloured highlighting in the learner model (left), indicates the correctness of the student's use of irregular plural nouns based on the learner model representations, next to native speaker or expert use (the system model: right). This is one method of encouraging learners to 'notice the gap' between their language and the language to which they have been exposed [29], as mentioned above. The authors give the example of 'loaves': using the highlighting technique shown in Figure 6, a learner's awareness may be raised to the fact that their own plural formation rule (e.g. the overgeneralisation that plural nouns are formed by adding 's' to the singular noun ('loafs'), is incorrect. They may further note that 'f' is replaced by 'ves', leading them to an awareness of the correct grammar rule: i.e. to form the plural of a singular countable noun ending in 'f', (usually) 'f' changes to 'v', and 'es' is added [26]. Such noticing of a language rule can help the integration of rules into the learner's own developing language system.

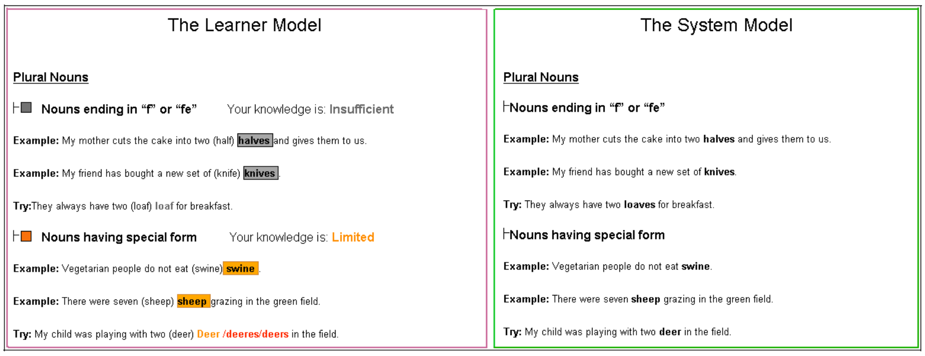

Fig. 6. The Notice OLM for language learning [26]

Notice was found able to facilitate immediate noticing of language elements (irregular plural nouns and irregular simple past verbs), much of which was retained in a delayed post-test one week after the experimental session (where no teaching of the target features had taken place in the meantime) [26]. While we do not know whether learners remembered the forms based on their interaction with the OLM, or whether they subsequently actively tried to notice or find out about the forms (as is one of the key aims of an independent OLM), it does appear that this kind of approach can be useful to prompt noticing in language learning. It will be interesting to explore the extent to which this may also apply in other subjects.

Negotiated learner models are interactive learner models that allow the student to negotiate the learner model contents with the system [31],[32],[33]. If the student disagrees with any of the system-inferred learner model data, they can challenge the system in an attempt to change the model, with each party required to justify their beliefs about the student's knowledge, through discussion. For example, the system may offer the learner the opportunity to compromise (i.e. agree on an intermediate representation of knowledge, if the system's and student's confidence in the learner's knowledge are sufficiently close to allow a compromise to be a reasonable action); the student may provide the information that they have forgotten certain concepts since their last interaction, indicating that the learner model has 'slipped backwards'; or that their understanding has increased due to a lecture or from reading undertaken between sessions with the system; the system may require the student to convince it to change its model by taking a short test to demonstrate their knowledge (or lack of knowledge); etc. The top of Figure 7 shows an excerpt of the display of learner confidence in their knowledge placed alongside the system's confidence in their knowledge, in order to highlight any differences to the learner; below is an excerpt from a student attempt to challenge the learner model in menu-based model negotiation in Mr Collins [31]. Such negotiation of the learner model is designed (i) to help improve the accuracy of the model by allowing the student to contribute information for consideration in the modelling process; and (ii) through the process of discussion of the learner's knowledge, to prompt learners to reflect on their understanding and develop a greater awareness of their learning needs. This also places some of the responsibility for the learning interaction, with the learner.

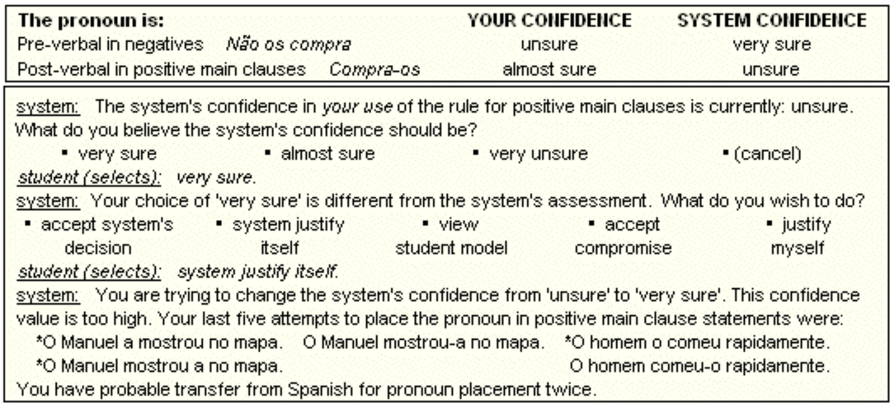

Fig. 7. Negotiating the learner model in Mr Collins [31]

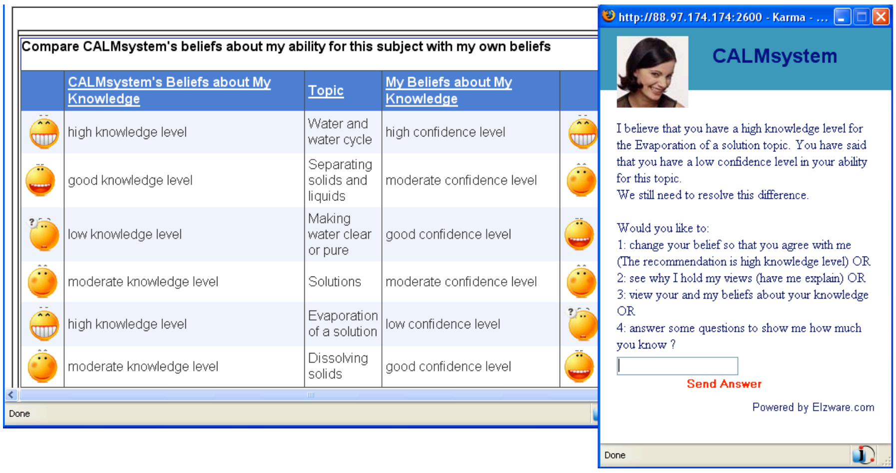

Fig. 8. Negotiating the learner model in CALMsystem [33]

In CALMsystem [33], the learner's level of knowledge of topics is displayed for comparison to the system's inferences about their knowledge (left of Figure 8). However, the model negotiation process is more flexible than in Mr Collins, using natural language in discussion with a chatbot (right of Figure 8). Statements such as the following to the chatbot (by 10-11 year olds), are indicative of self-monitoring: "but I need more work on it"; "I am getting better"; "I have changed my mind about my beliefs"; "can i change a belief [in the model] about separating solids and liquids please". A study over two sessions with children aged 10-11 in a science class, demonstrated significant improvements in self-assessment accuracy both in an inspectable-only condition (left of Figure 8) and a full negotiated learner modelling approach (both parts of Figure 8); and with significant improvements in the negotiated condition over the inspectable condition [33]. It appears, therefore, that use of a simple inspectable model for this age group can help learners, but the process of discussion of their knowledge can bring further benefits, and so could be recommended where such an approach would integrate well with the aims and interactions with a system.

As with Simprac [18],[19] in the previous ITS Section, and Notice [26] in this independent OLMs Section, OLMlets allows students to compare their knowledge against a standard. Here instructors input the expected level of knowledge for each stage of the course (defined by week, day or lecture number, as appropriate), and students can view their skill meters (or other representations) alongside the expected knowledge for the current stage of the course, to support their self evaluations and planning in the context of present expectations [24]. OLMlets also allows students to release their model data to their instructors, thus offering the benefits to teachers suggested above, in their use of independent OLMs; and has been shown able to promote spontaneous (face-to-face) peer discussion and help-seeking amongst students when they choose to release their learner models to each other [34]. This is therefore another common goal of metacognition researchers and open learner modelling researchers. Furthermore, an OLM designed to help parents help their children with fractions, was found also to highlight to parents, misconceptions that they themselves held about calculating fractions [35].

This section suggests that independent OLMs can in themselves enhance metacognitive behaviours related to the identification of knowledge, regulation of learning or planning of learning activities; and they can be used to prompt actions to facilitate learner independence.

2.3 Long-Term Open Learner Models

The examples above have all been associated with a rather limited context. In the life of the learner, we might build a quite comprehensive learner model that draws on the full range of evidence about the learner's progress. This learner model could then support reflection on long term learning, such as reading progress over the whole of primary school education or mathematics progress through the whole of school. A key value of such a model would be as an OLM for reflection by learners, perhaps in conjunction with their teachers and parents, to monitor progress, identify serious, long term problems and to plan learning.

3 Discussion: Links between Research Directions in Metacognition and Open Learner Modelling

We have described a range of approaches to open learning modelling, in terms of the relationship to an ITS and some of the forms that OLMs have taken. We have also identified several issues that are important for an OLM to provide effective support for metacognitive activities of reflection, self-monitoring, as well as planning and control of learning processes. If metacognitive skills were explicitly modelled by an ITS, an interactive OLM for these, too, could be the basis for a metacognitive activity and could provide an additional source of evidence about these skills in the learner's self-perceptions. An interactive OLM, which allows the learner to provide evidence about their knowledge directly to the OLM, is in line with a philosophy that encourages the learner to take control over and responsibility for their learning.

This workshop on metacognition identifies several themes, most of which can also be directly linked to OLMs. The first relates to *capturing, recording, or extracting metacognitive aspects of students' learning processes*. The log of student actions and interactions with their OLM could provide a key source of evidence about metacognition. The second theme is *interpreting and assessing metacognitive behavior*, which is precisely what we do when discussing an OLM with students, just as a classroom teacher might. Designing tasks for metacognitive assessment is a theme that is very naturally linked to OLMs. For example, a student can be asked to rate their own expertise and then be provided the system's corresponding assessment in the OLM. The theme, *evaluating the effect of metacognitive feedback and interventions*, poses a rather interesting new interface challenge for OLMs since it seems likely that a learner (and their human supporters, such as parents and teachers) may need new forms of interface that make it easy to see changes in the learner model in terms of such interventions. The next theme, *designing tasks for metacognitive assessment,* is completely congruous with OLM since the learner's interaction with their OLM is often just such a task. Some of the themes involve a combination of new approaches to building learner models, with the possibility that they also may bring new interface challenges. This is the case for: *measuring metacognition over time or in changing contexts* and is also true of the themes, *qualitative vs. quantitative methods to measure metacognitive behavior*, *modelling metacognition*, *assessing metacognition in educational technologies compared to the classroom or the lab*.

There is considerable potential for exploiting research on metacognition to inform work on OLMs as well as in the improved understanding of the ways that OLMs can support metacognitive processes and help develop metacognitive skills. We have distinguished two contexts for OLMs. When they are *within* an ITS, there is potential for careful design of the ITS and OLM, in terms of the interface and the underlying learning experiences so that there are immediate links between learning activities and the OLM. We have much to learn about the best ways to do this and how it may interact with many aspects, such as trust, gaming, exploration and toying with the ITS. We have also indicated some of the different possibilities and issues for a learner model that exists *outside* a particular ITS and the ways that its OLM interfaces might support and encourage metacognitive activities. In both of these roles, OLMs can serve several purposes, most being strongly linked to metacognitive activities of reflection, monitoring progress, planning both in the short and long term, and aiding the learner in taking responsibility and control of their own learning and progress.

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The Learner Modelling for Reflection (LeMoRe) group is interested in all aspects of learner modelling designed to promote or model learner reflection; a major interest being open learner models. See http://www.eee.bham.ac.uk/bull/lemore.

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