

An Open Learner Model for Children and Teachers: Inspecting Knowledge Level of Individuals and Peers

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Abstract. This paper considers research on open learner models, which are usually aimed at adult learners, and describes how this has been applied to an intelligent tutoring system for 8-9 year-old children and their teachers. We introduce Subtraction Master, a learning environment with an open learner model for two and three digit subtraction, with and without adjustment (borrowing). It was found that some children were quite interested in their learner model and in a comparison of their own progress to that of their peers, whereas others did not demonstrate such interest. The level of interest and engagement with the learner model did not clearly relate to ability.

1 Introduction

There have been several investigations into open learner models (OLM). One of the aims of opening the learner model to the individual modelled, is to encourage students to reflect on their learning. For example, Mr Collins [1] and STyLE-OLM [2] employ a negotiation mechanism whereby the student can debate the contents of their model with the learning environment, if they disagree with the representations of their beliefs. This process is intended to help improve the accuracy of the learner model while also promoting learner reflection on their understanding, as users are required to justify any changes they wish to make to their model, before these are incorporated.

Mitrovic and Martin argue that self-assessment is important in learning, and this might be facilitated by providing students access to their learner model [3]. Their system employs a simpler skill meter to open the model, to consider whether even with a simple learner model representation, self-assessment can be enhanced. They suggest their open learner model may be especially helpful for less able students.

The above examples are for use by university students, who can be expected to understand the role of reflection in learning. Less research has been directed at children's use of OLMs, and whether children might benefit from their availability. One example is Zapata-Rivera and Greer, who allowed 10-13 year-old children in different experimental conditions to browse their learner model, changing it if they felt this to be appropriate [4]. They argue that children of this age can perform self-assessment and undertake reflection on their knowledge in association with an OLM. In contrast, Barnard and Sandberg found that secondary school children did not look at their learner model when this was available optionally [5].

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Another set of users who have received some attention, are instructors - i.e. tutors can access the representations of the knowledge of those they teach. For example, in some systems the instructor can use their students' learner models as a source of information to help them adapt their teaching to the individual or group [6], [7].

Kay suggests users might want to see how they are doing compared to others in their cohort [8]. Linton and Schaefer display a learner's knowledge in skill meter form against the combined knowledge of other user groups [9]. Bull and Broady show co-present pairs their respective learner models, to prompt peer tutoring [10].

Given the interest in the use of various forms of OLM to promote reflection by university students, both by showing them their own models and in some cases, the models of peers; and work on showing learner models to instructors, it would be interesting to extend this approach to children and teachers. Some work has been undertaken with children [4], [5], but we wish to consider the possibilities for younger students. We therefore use a simple learner model representation.

We introduce Subtraction Master, an intelligent tutoring system (ITS) for mathematics for use by 8-9 year olds. Subtraction Master opens its learner model to the child, including a comparison of their progress against the general progress of their peers; and opens individual and average models to the teacher. The aim is to investigate whether children of this age will sufficiently understand a simple OLM and, moreover, whether they will want to use it. If so, do they wish to view information about their own understanding, and/or about how they relate to others in their class? Will they want to try to improve if their knowledge is shown to be weak?

2 Subtraction Master

Subtraction Master is an ITS with an OLM, for 8-9 year-olds. The aim of developing the system was to investigate the potential of OLMs for teachers and children at a younger age than previously investigated. The domain of subtraction was chosen as there is comprehensive research on children's problems in this area [11], [12].

Subtraction Master is a standard ITS, comprising a domain model, learner model and teaching strategies. The teaching strategies are straightforward, selected based on a child's progress, with random questions of appropriate difficulty according to their knowledge. Questions also elicit further information about misconceptions if it is inferred that these may exist. Additional help can be consulted at any time, and can also be recommended by the system. Help is adaptive, related to the question and question type the child is currently attempting, and is presented in the format most suitable for the individual. This section provides an overview of the system.

2.1 The Subtraction Master Domain

The domain is based on the U.K. National Numeracy Strategy [13], incorporating common calculation errors and misconceptions. The domain covers 2 and 3 digit subtraction, ranging from 2 digit no adjustment (borrow), to 3 digit hundreds to tens adjustment, tens to units adjustment. Specifically, the following are considered:

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- two digit subtraction (no adjustment) e.g. 23-12
- two digit subtraction (adjustment from tens to units) e.g. 76-28
- three digit subtraction (no adjustment) e.g. 459-234
- three digit subtraction (adjustment from tens to units) e.g. 574-359
- three digit subtraction (adjustment from hundreds to tens and tens to units) e.g. 364-175

2.2 The Subtraction Master Learner Model

The learner model contains representations of knowledge of the types of subtraction given above, and misconceptions of the individual user, drawn from a misconceptions library. The possible misconceptions modelled by the system are:

- misconception - *commutative*: 5-7 is treated the same as 7-5 (the smaller number is always subtracted from the larger. Thus $23-18=15$)
- misconception - *place value*: borrowing from the wrong column (in 410-127, 4 is decreased to 3 and 1 is inserted at the head of the units column; then 3 is decreased to 2 and 1 is inserted at the head of the tens column)
- misconception - *zero has no effect*: 0-5 is treated the same as 5-0 (similar to commutative, but occurs only with zero. 13-5 would be answered correctly)
- bug - *addition completed rather than subtraction*: $7-5=12$
- bug - *place value incorrect due to incorrect transcription of calculation*: working out the answers on paper, children transcribe figures incorrectly

As stated above, the primary aim is to investigate the potential of open learner models for children. Thus the focus of Subtraction Master is not as complex as would be suggested by investigations such as those of Brown and Burton [11] and Burton [12]. OLMs will be investigated in the context of more complex ITSs if this seems warranted after the initial investigations with simpler environments.

In addition to explicit misconceptions, representations of skill level are as follows:

- question type: level 1 (question type not attempted, or no correct answers, or incorrect responses outweighing correct answers)
- question type: level 2 (question type attempted, at least one correct, no misconceptions)
- question type: level 3 (below 40%, some correct, little evidence of misconceptions)
- question type: level 4 (40%-50% correct, little evidence of misconceptions)
- question type: level 5 (above 50% correct, little evidence of misconceptions)

'Question type' refers to the kind of question (e.g. two digit subtraction, no adjustment). The 'level' indicates the child's proficiency in that question type, with 5 being the most advanced. The definitions of level are arbitrary at this stage - the intention is to provide encouraging feedback through the OLM, in accordance with classroom teaching practice. Thus progression through levels can be achieved reasonably easily.

Level 1 indicates that a question type has either not been attempted, that the child has not answered any of those questions correctly, or that their incorrect answers and misconceptions outweigh their correct responses. For level 2 the learner must have answered at least one question correctly, and displayed no misconceptions. This allows a more positive representation (than level 1) for a learner without misconcep-

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tions, but who has not yet answered enough questions to reach level 3 (i.e. there is insufficient evidence to place them at level 3). In subsequent levels (3-5) it is possible that the child will have exhibited a misconception; however, their correct responses will outweigh any misconceptions. The data in the learner model is associated with a degree of certainty, depending on the extent of evidence available to support it.

2.3 The Subtraction Master Teaching Strategies

The subtraction explanations are animations of the standard decomposition method where figures are crossed out and decreased for 'borrowing', and expanded decomposition where figures are broken into tens and units, to reinforce place value (e.g. 47 is written as 40 and 7). A number square (a square of numbers from 1-100) is used if a child is unsuccessful with the decomposition methods. The form of explanation is that inferred most suitable to help a learner overcome a problem. The target is the standard decomposition method, as this is achievable by children of this age (i.e. it is currently taught by the teacher). Help screens are available for consultation at any time. Where the system detects the child is having difficulty, it prompts them to use help.

The questions offered increase in difficulty as the child progresses successfully. Where there are problems, the system guides the child through the subtraction process. If a possible misconception is detected, further questions are selected to elicit data on the likelihood of the child holding that misconception.

3 The Subtraction Master Open Learner Model

This section presents the open learner model as seen by children and teachers.

3.1 The Subtraction Master Open Learner Model for Children

The OLM can be accessed as a means to raise children's awareness of their progress, using a menu or buttons. These are labelled: 'see how you are doing' and 'compare yourself to children of your age'. The individual learner model is displayed in Fig. 1.

The children have not yet learnt about graphs, therefore the learner model data cannot be presented in that form. Instead, images are used, that correspond to the skill levels for each question type:

- (level 1: *no image*, not attempted / none correct / weak performance)
- level 2: *tick*, satisfactory
- level 3: *smiling face*, good
- level 4: *grinning face*, very good
- level 5: *'cool' grinning face with sunglasses*, fantastic

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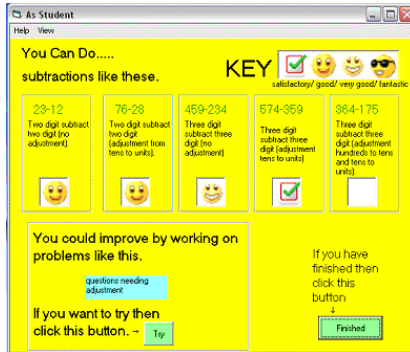


Fig. 1. The individual learner model

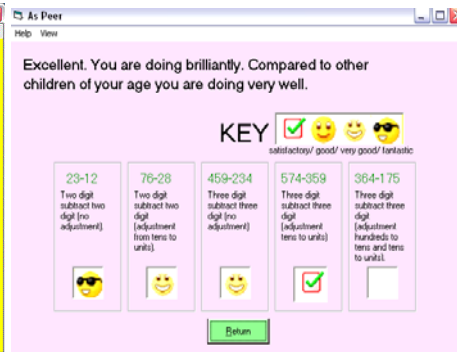


Fig. 2. Comparison to the average peer

Weak performances are not shown. A blank square might mean the child has not attempted questions of that type, or they have performed badly. This avoids demotivating children by showing negative information. Their aim is to 'achieve faces'.

If the child chooses 'compare yourself to children of your age', they can view the model of themselves compared to the 'average peer', as in Fig. 2. In this example, the child is doing extremely well compared to their peers in the first question type, indicated by the grinning face with sunglasses; and very well with the second and third types. They are performing in line with others in the fourth. However, in the final type, there is no representation. In this case this is because the child, and the class as a whole, have not yet attempted many questions of this kind. Where a child was not doing well compared to others, there would also be no representation. The aim is that the child will want to improve after making this comparison to their peers.

After 20 questions, the child is presented with their individual learner model and offered the chance to improve specific areas if these have been assessed as weak (bottom left of Fig. 1). This may be simply where they are having most difficulty, or where misconceptions are inferred, or it might be where the system is less certain of its representations. This is in part to encourage those who have not explored their learner model, to do so, and in part to guide learners towards areas that they could improve. While guidance occurs during individualised tutoring, this prompting within the OLM explicitly alerts learners of where they might best invest their effort.

In systems for use by adults, an approach of negotiating the learner model has been used [1], [2], to allow learners to try to persuade the system that their perception of their understanding is correct, if they disagree with the system's representations in the model. One way in which they can do this is to request a short test to prove their point. Since negotiation with a system over one's knowledge state is quite a complex procedure, this may not be appropriate for younger children. Thus the idea of a brief test to provoke change in the model if a child disagrees with it, is maintained in Subtraction Master, but the possibilities for adjusting the model are suggested by the system. The child can take up the challenge of a test if they believe they can improve the representation in their learner model; or they can accept the test while at the same time working through further examples to improve their skills in their weaker areas. The former quick method of correcting the model is useful, for example, if a child

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suddenly understands their problem. This can be illustrated with an example from one of the children in the study (see section 4), who showed misconceptions about commutative laws. On viewing help, she exclaimed 'I got it, I keep changing the numbers around instead of borrowing'. The student's learner model contained a history of the problem. When offered a test to change the model contents, she accepted and managed to remove the problem area from her model. She therefore did not have to complete a longer series of questions in order for the model to reflect this progress.

3.2 The Subtraction Master Open Learner Model for Teachers

Teachers can access the models of individuals, or they can view the average model of the group. Figs. 3 and 4 show the teacher's view, that can be accessed while they are with the child during the child's interaction, or later at their own PC. Teachers can edit the model of any individual if they believe it to have become incorrect (such as when a child has suddenly grasped a concept during coaching by the teacher, or if new results from paper-based testing are available, etc.). I.e. teachers can update the model to improve its accuracy, in order that the system continues to adapt appropriately to meet children's needs if they have been learning away from Subtraction Master.

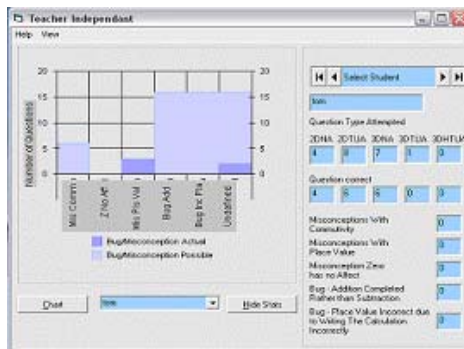


Fig. 3. The teacher's view of the individual



Fig. 4. The teacher's view of the individual compared to the group

Children are not shown misconceptions. However, this may be useful data for teachers. Figs. 3 and 4 show the learner model of Tom. Fig. 3 illustrates areas in which he could have shown misconceptions given the questions attempted (shaded light), and the misconceptions that were observed (shaded dark). The last column shows 'undefined' errors. In the above example, from a possible 15 undefined errors (15 questions were attempted), 2 undefined errors were exhibited. 3 incorrect responses suggest a likely place value misconception, out of 3 questions attempted, where this problem could be manifested (column 3). The first column shows Tom answered 6 questions where he could have shown a commutative error, but did not.

The upper portion of the right side of the screen shows Tom's performance across question types (number attempted, number correct). Below this is the strength of evidence for the five types of misconception or bug. As can be seen by the figure for

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place value being 0, the teacher has edited the model to reflect the fact that Tom no longer holds this misconception after help from the teacher.

Fig. 4 shows Tom's performance against the average achievement of the group. The group data can also be presented without comparison to a specific individual. Thus teachers can also investigate where the group is having most difficulty.

4 Benefits of a Simple Individual and Peer OLM for Children

We here present an overview of a study of potential benefits of the Subtraction Master OLM for children. The following questions were of particular interest:

- Would children want to view their learner model?
- Would children want to view the peer comparison model?
- Would children be able to interpret their learner model?
- Would children be able to interpret the peer comparison model?
- Would children find the open learner model useful?

4.1 Subjects

Subjects were 11 8-9 year-olds at a Birmingham school, selected by the Head Teacher to represent high achievers (4), average (2), low achievers (5); with 6 boys and 5 girls spread quite evenly in the high and low groups. Both average pupils were boys.

4.2 Materials and Method

Audio recordings were made while children used Subtraction Master. They were sometimes prompted for further information. Written notes were made to provide contextual information. Additional information was obtained by structured interview after the interaction. Sessions lasted around half an hour.

4.3 Results

Table 1 shows use of the open learner model by children. Students are listed in sequence as ranked for ability by the Head Teacher, from lowest to highest.

Table 1. Use of the open learner model by children

Use of OLM	Low Achievers					Average		High Achievers			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
little or none		x		x	x				x		
spontaneous	x		x			xx	x	x		xx	x

Four children made little or no use of their OLM after the first inspection, while 7 returned to it spontaneously - 2 using it extensively (S6 and S10). There is no clear

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relationship between ability and preference for viewing the learner model, though in general it appears that the higher ranked students tend to be more interested. However, the lowest ranked child did use their model, and the third highest did not.

Transcripts of children's comments while using the OLM suggest many understand and benefit from it, illustrated by the following. (E=experimenter, S=subject.)

E: [Asks about the open learner model]

S1: Well at first that little face and then afterwards the big face was there.

E: And what did that mean to you?

S1: That I know my maths better.

S10: [Of the peer model] They are very good. I know they are both good because I have only had one of those ones and I had one of those other ones.

E: Can you think of a reason why you have one of those?

S10: Because other people have done more and they did it more times than me at the moment, and I have only done one ... So mine would go up when the next person gets one of them wrong.

.....

E: You kept checking the models of yourself compared to others and perhaps compared to a test if you were taking a test. Why did you keep doing that?

S10: To see how I was doing.

S11: How good am I doing [compared] to the other pupils?

.....

S11: The average people have got this face on, and that's a bit over average, and that's really over average, and that's less than average a bit.

E: [Asks about the peer model]

S11: Encourage me to do better actually, see how people are getting on, try to work hard, improve on last year or if we have to do another test ... I liked that.

The more able pupils (S10, S11) are better able to articulate their understanding of the OLM, and appreciate what is represented, even by the peer model. S1, ranked lowest, also used the OLM. It was harder to get S1 to freely express his views, but the excerpt shows he understood the individual model, as revealed upon prompting.

A chance occurrence further demonstrated a child's appreciation of the meaning of his learner model. Whilst S6 ('average') was working, his mother (a classroom assistant) asked how he was getting on. He looked at his learner model and replied 'great'.

4.4 Discussion

Our aim was not to develop a full ITS, but rather to investigate the potential for using OLMs with 8-9 year olds. Hence the system is relatively simple. We recognise that using only 11 subjects, our results are merely suggestive. It does seem, however, that the issue of using OLMs with children of this age, is worth investigating further.

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We return to the questions raised earlier: Would children want to view their learner model? Would children want to view the peer comparison model? Would children be able to interpret their learner model? Would children be able to interpret the peer comparison model? Would children find the open learner model useful?

There appears to be a difference between children in their interest in the OLM. Seven children chose to use their model on more than one occasion, with 2 using it extensively. These two kept referring back to their model to monitor their progress. For them, the OLM was clearly motivating. One was high ability, and the other, medium ability. Thus the OLM can be a motivating factor for at least these two levels of student. The remaining 5 children who used their learner model spontaneously were two low-achievers, the other medium-level student, and two further high-achievers. The model therefore appears of interest to children of all abilities, though in general the higher level children had a greater tendency to refer to their learner models.

Of the 4 children who did not use their learner model, 2 were also disinterested in learning with computers generally (S2 and S5). Thus it may be this factor rather than the learner model itself, that is the basis of their lack of use of their learner model.

In addition to observations of students returning to their models, the transcript excerpts from low and high ability children demonstrate that 8-9 year olds can understand simple learner model representations. S1, the child with most difficulties, articulated his views only after prompting, but nevertheless showed an understanding of the learner model, albeit at a simple level. S10 and S11, high ability students, gave spontaneous explanations. The excerpts given, show their views of the comparative peer model. Both wanted to check their progress relative to others. S11 spontaneously asked how other children were doing before viewing the peer model. When the peer model was then shown to him, he became particularly interested in it. S6, an average student, referred to his learner model in order to report his progress to his mother.

The above questions can be answered positively for over half the children, as noted in the structured interview and student comments while using Subtraction Master. There was a tendency for higher- and medium-ability children to show greater interest, but two of the five lower-ability children also used their learner model.

We do not know to what extent the results are influenced by the novelty of the approach to the children, and the fact that they were selected for 'special treatment'. This needs to be followed up with a longer study with a greater number of subjects, which also considers learning gains. (A short pre- and post-test were administered, showing an average 16% improvement across subjects, but due to the limited time with the children, extended use of the system and delayed post-test were not possible.)

5 Summary

This paper introduced Subtraction Master, an ITS for subtraction for 8-9 year-olds. It was designed as a vehicle for investigating the potential of simple individual OLMs and comparison of the individual to peers, to enhance children's awareness of their progress. The children demonstrated an understanding of their learner model, and 7 of the 11 showed an interest in using it. These had a range of abilities. The next step is to allow children to use the system longer-term, to discover whether this level of interest

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is maintained over time, and if so, to develop a more complex ITS and investigate further open learner modelling issues with a larger number of children.

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