Use and Trust of Simple Independent Open Learner Models to Support Learning Within and Across Courses

Susan Bull[1], Peter Gardner[1], Norasnita Ahmad[1], Jeffrey Ting[2] and Ben Clarke[1]

[1] Electronic, Electrical and Computer Engineering, University of Birmingham, UK
[2] Centre for Learning, Innovation and Collaboration, University of Birmingham, UK
{s.bull, p.gardner, nxa707, i.h.ting, b.j.clarke}@bham.ac.uk

Abstract. This paper introduces two independent open learner models (learner models that are accessible to user viewing), which are deployed alongside university courses to facilitate self-assessment skills, planning and independent learning. OLMlets is used in specific courses, while UK-SpecIAL, a modular extension to OLMlets, draws on the OLMlets learner models to display progress towards achieving learning outcomes applicable across courses. User logs demonstrate usage of each system, and questionnaire responses provide insight into the reasons for user trust in the environments.

Keywords: Open learner models, learner independence, user trust

1 Introduction

Trust has been considered in a variety of fields. In psychology, for example, trust relates to personal qualities pertaining to the beliefs and expectations of the individual [1], whereas in sociology it tends to be regarded as a mutual relationship [2]. In human-computer interaction, an important question is whether a system inspires user confidence in its actions/decisions/recommendations, etc., to the extent that users will act on these [3]. In this paper our focus is on user trust in environments that open the learner model to the user, and use of such environments. A learner model that is open to learner inspection might help contribute to the development of student trust in a system, as users will be able to see (some of) the information on which it bases its inferences [4]. However, users will need to accept the information about their knowledge and understanding, if they are to act appropriately on the information that they find in their learner model. Accuracy of the model, utility of the model for promoting learning, and user trust in their learner model have all been identified as key features in open learner modelling in the SMILI Open Learner Modelling Framework [5]. We here aim to draw these components of the framework together. We define trust in this context as: "the individual user's belief in, and acceptance of the system's inferences; their feelings of attachment to their model; and their confidence to act appropriately according to the model inferences" [6]. Previous work suggests students view trust in this context in a similar way [7].

In student-centred learning, learners are encouraged to recognise their learning needs and manage their own learning, extending and deepening their knowledge using

G-J Houben, G McCalla, F Pianesi & M Zancanaro (eds),
User Modeling, Adaptation and Personalization,
Springer-Verlag, Berlin Heidelberg, 2009, 42-53

a range of activities [8]. The U.K. Higher Education Academy encourages the development of metacognitive skills such as self-assessment and reflection in university education [9]. Externalising a system's model of the learner to the user, as well as helping to promote trust in a system's actions, can help prompt learner reflection and metacognitive skills [10]. Student self-knowledge is argued to be particularly important for self-directed learning or student-centred learning in the context of open learner models (OLM) [11]. This draws on key works on student reflection in the general education literature (e.g. [12],[13]).

Externalisation of user knowledge in an OLM can be simple or complex. Complex presentations can show hierarchical, prerequisite, conceptual and other relationships in or between knowledge (e.g. [11],[14],[15],[16],[17]), and can be a useful way to provide structured externalisations of learner knowledge in a domain-specific context. Simple model displays, whilst perhaps based on complex underlying learner models, use less complicated externalisations. The most common are 'skill meters' indicating the extent of current knowledge, mastery or understanding of a topic or concept, and have enjoyed widespread use in real settings (e.g. [18],[19],[20]), suggesting learners find them easy to interpret and useful as a learning support. Early investigations suggest simple learner model displays may be trusted by users, perhaps because it is clear to them, what the representations show [6]. User trust may be especially important when *independent* open learner models (IOLM) are used. IOLMs are OLMs that are the focus of an interaction, separate from the other, standard components of intelligent tutoring systems (domain and pedagogical model) [18]. Learner modelling occurs in the usual way (e.g. based on problem-solving attempts, responses to questions, help or hints requested, navigation, time on task). The user then accesses their learner model in order to determine how to proceed - i.e. the responsibility for the decisions in learning rests with the learner (see [11]). The IOLM approach aims specifically to promote metacognitive skills considered crucial to the development of successful and critical approaches to learning, as introduced above.

The OLMlets simple IOLM has been taken up by 2/3 of students across all courses in which it is available in the School of Electronic, Electrical and Computer Engineering, University of Birmingham. (Range: one 1/6 of students in an individual course, to all students taking a course, and this applies across all stages of the degrees [18].) In this paper we introduce a new component linked to OLMlets: UK-SpecIAL, which unites information about learning outcomes across courses in students' degrees. We investigate the utility of UK-SpecIAL in its situation of use with OLMlets.

In the following section we describe the requirements of U.K. engineering degrees, to present the pedagogical context within which our approach is deployed. In Section 3 we present OLMlets and UK-SpecIAL, and conclude with an evaluation of these systems in Section 4, considering levels of use and user trust. Whilst we describe a specific application, the approach may be relevant in a range of degree subjects.

2 Requirements of Engineering Degrees

In order to obtain accreditation for engineering degrees in the U.K., the UK SPEC Standard for Professional Engineering Competence [21] must be demonstrated. UK

SPEC covers five broad areas: (i) underpinning science and mathematics; (ii) engineering analysis; (iii) design; (iv) economic, social and environmental context; (v) engineering practice. Each of these areas is further broken down into specific learning outcomes for students, for example, "engineering analysis" includes: "ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline"; "understanding of engineering principles and the ability to apply them to analyse key engineering processes". "Engineering practice" includes: "awareness of nature of intellectual property and contractual issues"; "ability to work with technical uncertainty". These learning outcomes differ from the format commonly used within courses to describe intended learning outcomes to students (e.g. "on successful completion of this module you will be able to: design.../select.../solve..." (see [22])). The UK SPEC learning outcomes have been interpreted specifically for electrical, electronic and computer engineering degrees by the U.K. Institution of Engineering and Technology (IET) [23].

Figure 1 illustrates how several courses contribute to a single UK SPEC learning outcome, showing first year courses that contribute to UK SPEC learning outcome: "Knowledge and understanding of scientific principles and methodology necessary to underpin their education in their engineering discipline, to enable appreciation of its scientific and engineering context, and to support their understanding of historical, current, and future developments and technologies". This learning outcome has been interpreted by the IET for degrees in its area of specialism as learning outcome B1. (The text associated with each course in Figure 1 is taken from that IET detail.)

Figure 2 shows as an example, the full set of UK SPEC learning outcomes to which a specific first year course, EE1A: Digital Logic and Microprocessor Systems, contributes. Again, words from the IET interpretation of UK SPEC are included to show which particular aspects of each learning outcome are addressed.

Figure 3 gives an example of the overall picture across all the years of the programme, by showing which courses contribute to the UK SPEC learning outcome "Understanding use of technical literature and other information sources". The IET interprets this as B22, requiring students to demonstrate "Familiarity in obtaining, searching and interpreting technical literature and other documentation from various sources". This is a clear example where it would be unrealistic to expect that the learning outcome to be addressed, would be met and demonstrated within a single course. Furthermore, there are differences in the ways in which these courses contribute to this learning outcome, as the courses are quite diverse. For example, in the first year course EE1A: Digital Logic and Microprocessor Systems, students need to make use of manufacturers' technical data sheets for microprocessors in order to complete laboratory assignments and exam questions. In the second year EE2H2: Personalisation and Adaptive Systems course, students engage with the literature on user modelling and adaptive hypermedia in order to inform (and provide justification for) their own questions and designs for adaptive systems with various functions (e.g. recommending products, supporting learning, tailoring information presentation [24]). Courses beginning with 'EE1' indicate first year courses; 'EE2', second year courses; and 'EE3', third year courses. For BEng undergraduate students, the third year is their final year of study. For MEng undergraduate students, the fourth year is their final year. In Figure 3 we have omitted the relevant fourth year courses (except for the individual project), for clarity.

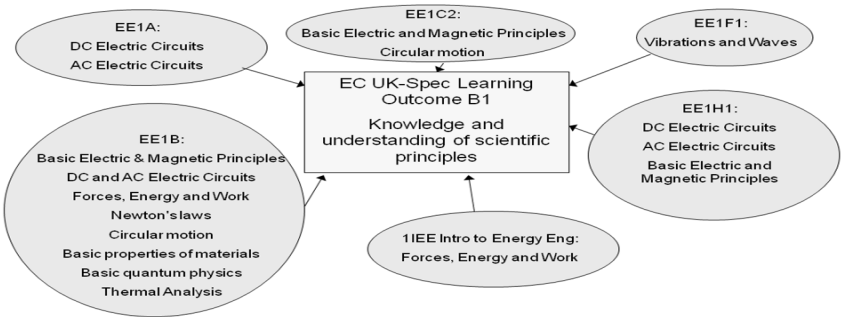

Fig. 1. Contribution of first year courses to UK SPEC learning outcome B1

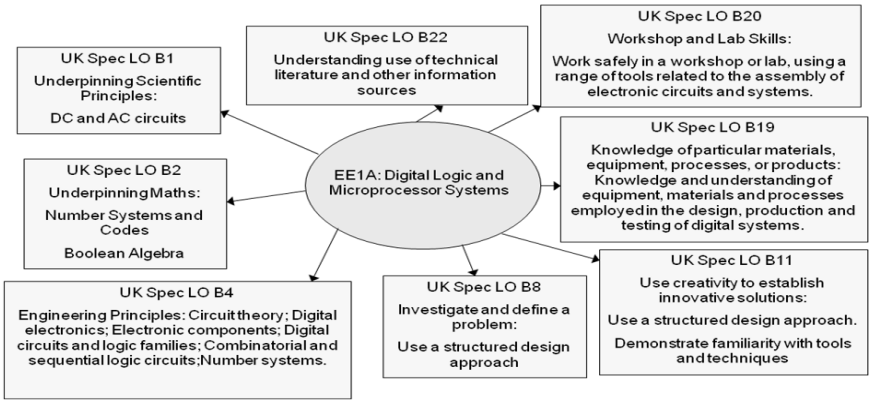

Fig. 2. UK SPEC learning outcome to which course EE1A contributes

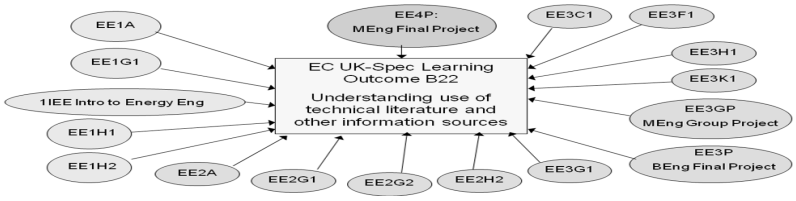

Fig. 3. Courses in all years that contribute to UK SPEC learning outcome B22

3 Simple Open Learner Models Within and Across Courses

This section presents (i) OLMlets, an IOLM used within courses; and (ii) UK-SpecIAL, an IOLM that shows progress towards learning outcomes across courses in a degree, based on UK SPEC.

3.1 OLMlets: Knowledge of Topics or Concepts Within a Course

OLMlets has been in use in the School of Electronic, Electrical and Computer Engineering, University of Birmingham, for four years. Trialled initially in five courses in its first year of deployment [25], OLMlets is now available to support 18 courses across all levels of the degree. OLMlets is written in the PHP scripting language, and data is stored with the MySQL relational database engine. The application is hosted via an Apache web server running on a Sun Solaris system.

Learner modelling takes place according to course topics defined by the course instructor [25]. These topics may be as focussed or as general as the instructor wishes. For example, the second year Personalisation and Adaptive Systems course uses broad topics based on Jameson's user modelling classification: functions of user models; user properties modelled; obtaining user model information; user modelling techniques [24]; and other general user modelling issues including the differences between adaptable and adaptive systems. The first year Introduction to Circuits, Devices and Fields course defines more focussed areas, for example: electron and hole motion in a semiconductor; the relationship between electric field and voltage in simple devices; the relationship between current and voltage in a resistor. For each course, modelling occurs over the previous five attempts at multiple choice questions on a topic or concept, where response options include those indicating common errors or misconceptions in the subject. For example, for the Personalisation and Adaptive Systems course: that recommender systems necessarily know about the objects they are recommending (the modelling technique must be content/knowledge-based). Each topic or concept is stored in the underlying learner model with a figure in the range 0-1 to indicate level of current understanding of the topic; and a figure in the range 0-1 to indicate the likelihood of the learner holding each misconception defined by the instructor. Weighting of the contribution of each response in the learner model, across the last five attempts at questions on a topic or concept, increases by 0.3 each time. Thus, greater weighting is given to the most recent attempts. The modelling is necessarily simple, as OLMlets is used in a variety of courses having different structures and different conceptual relationships, and can be used in any subject for which appropriate multiple choice questions can be defined.

Figure 4 shows two ways to access the overview of their knowledge level available to students from within a course, in a first year course addressing general engineering and writing skills, which is designed to help students transfer these skills to meet the requirements of other courses. The course uses five topics (open-ended academic arguments; Birmingham Harvard referencing format; general plagiarism issues; ethics and professional engineering issues; health and safety).

Colour is used in the 'skill meters' view of the learner model to indicate strength of knowledge, gaps or problematic knowledge and misconceptions (brief descriptions of misconceptions can be obtained by clicking on the 'misconceptions' link - shown in Figure 4 for topic 2). The second set of skill meters indicates the learner's current knowledge, and the first set, the knowledge expected by the instructor for the present stage of the course. The 'boxes' view also uses colour: various shades of green to indicate strength of knowledge in the large boxes for each topic, and equivalent shading for the smaller boxes underneath each large box, to show the instructor's current expectations. (The 'Q' icons lead to further questions on a topic; the 'M' icons

to course materials on the topic.) In total there are five views, also: graph, ranked list in table form, and text overview of knowledge level [25]. The purpose of the multiple views is to allow the learner to select the format that most suits them, based on previous findings suggesting that students may have differing preferences for the presentation format of their learner model contents [15].

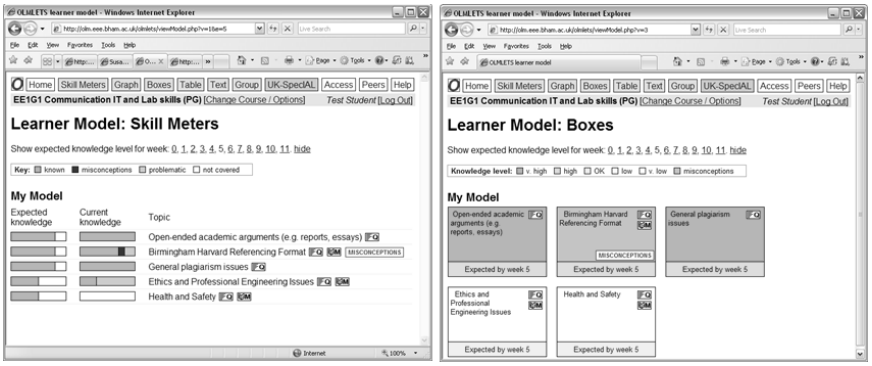

Fig. 4. The OLMlets open learner model (knowledge of topics or concepts within a course)

Students can choose to release their learner model to instructors and/or peers, in named or anonymous form. They may view the learner models of those people who have made their model available, alongside their own model.

3.2 UK-SpecIAL: UK SPEC Learning Outcomes Across Courses

Forms of assessment using e-learning have been argued as useful additional support in today's outcomes-focused or objectives-focused educational systems [26]. For example, in engineering EASIMAP [27] maps UK SPEC learning outcomes to achievements, with reference to lecturers' assessment of a student's learning (learning outcomes are included on a grid, and student progress towards these is indicated after assessments have been completed). UK-SpecIAL (UK SPEC Independent Adaptive Learning) follows a complementary approach, focussed on formative assessment and helping students to identify their learning needs. The approach stresses the learner's current understanding as represented in their learner model, as a starting point for them to note any gaps in their knowledge and in their progress towards achieving the UK SPEC learning outcomes. This aims to help inform their decisions on how to focus their efforts across courses. In line with many other IOLMs, a primary purpose is to promote reflection, and encourage the development of independent learning skills and responsibility for one's own learning, but it also aims to address the problem of students sometimes not understanding how the various components of their degree fit together, at the time they are studying them [28].

UK-SpecIAL was developed as a modular extension to the OLMlets web application. It draws on the OLMlets learner models described above. The model data for each of the topics in an OLMlets course is averaged, resulting in a single figure (in

the range 0-1) for each course. This figure is translated to the colour scheme in Figure 5 for presentation to the user: shading indicates the overall level of understanding of a course in a 'boxes' view; each course is then listed under the UK SPEC learning outcome to which it contributes. A course is listed as many times as the number of learning outcomes to which it applies (see Figure 6 for the relationship between OLMlets and UK-SpecIAL). Thus users can see immediately, which courses contribute to which learning outcomes, and their own relative progress in each course. Clicking on a course title displays the specific UK SPEC learning outcomes to which the course is relevant. For example, for the first year EE1A course Digital Logic and Microprocessor Systems, under learning outcome B20 Workshop and Laboratory Skills, the following is shown: "Work safely in a workshop or lab, using a range of tools related to the assembly of electronic circuits and systems" (illustrated in Figure 5). Clicking on this course title under a different learning outcome will display text applicable to that learning outcome (see Figure 2 for examples).

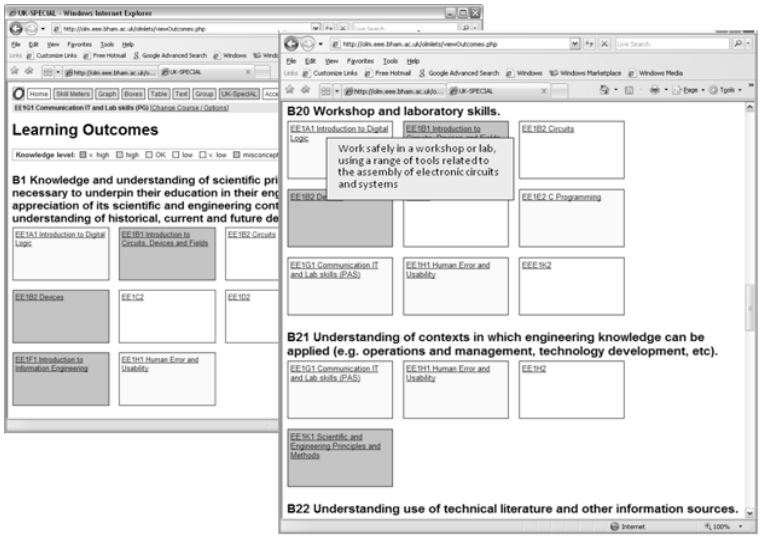

Fig. 5. The UK-SpecIAL open learner model (UK SPEC learning outcomes across courses)

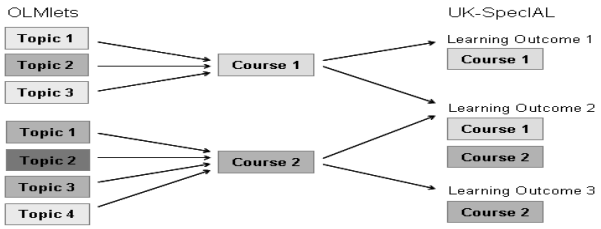

Fig. 6. OLMlets and UK-SpecIAL

4 Use and Trust of OLMlets and UK-SpecIAL

This section introduces the results of use of OLMlets and UK-SpecIAL across a term in first year courses, and student trust in the two systems.

4.1 Participants, Materials and Methods

Participants were 86[1] first years in Electronic, Electrical and Computer Engineering, University of Birmingham, U.K. Students were familiar with OLMlets from several courses. UK-SpecIAL was briefly introduced in a lab session in one of the courses (n=69). Students used the systems in their own time as they felt appropriate, during a term. The OLMlets learner models were assessed at the end of 2 courses (contributing 7% and 10% to the course mark), but use was optional in the other 6 courses. Interactions are automatically recorded, and provide an anonymous user log. Table 1 gives an example of an access to UK-SpecIAL by user 955, from OLMlets course 25. The unique user number is automatically assigned on creation of an account.

Questionnaires were completed in one of the courses. Responses were on a 5-point scale: 5 strongly agree, 4 agree, 3 neutral, 2 disagree, 1 strongly disagree, with space for additional comments. 23of the 66 students responded to an email sent a few weeks after the course, for consent to use their questionnaire data in this research.

Table 1. Example from user log

event_id	time	user_id	course_id	event_type	field_1
316463	2008-11-29 16:17:44	955	25	8	UK-SPECIAL

4.2 Results

Table 2 shows log data across all OLMlets courses in which students were registered (mean 4, median 4, range 1-6). 86 students attempted questions. The greatest use was in one of the courses that assessed the learner models, and the other course with assessed models had the third highest usage level, amonst the first year courses. Users attempted 577 questions on average (median over 400). The individual learner models were accessed on average 400 times (median over 300), by nearly all users (n=84). 54 also compared their knowledge to instructor expectations (mean 19.5, median 14.5 times), available in 5 courses; and 79 accessed UK-SpecIAL (mean 6.7, median 5). 66 accessed UK-SpecIAL multiple times. (Of these, mean access was 8, median 6.) 42 released their models to others; 44 viewed peer models that were accessible to them.

The mean and median figures in Table 3 show most students claimed to understand their OLMlets model, believed it an accurate representation of their understanding, and found it helpful in identifying their knowledge. Students claimed to trust the

[1] This figure includes data from a *demo user* (that interacted minimally), that was not removed because of anonymous logs; and users who were not first years who may have registered by mistake, or may have been revising first year content. (There are 82 current first years.)

OLMlets information in general, and specifically because they could see its inferences about their knowledge, because they could make comparisons between their own knowledge and that of other users and, in particular, because they could compare their current understanding against the expectations for the current stage of the course.

Table 4 shows that most students also understood the UK-SpecIAL information, considered it reasonably accurate and felt it helped them identify their knowledge, but to a lesser extent than OLMlets. They judged it useful to help identify relationships (of learning outcomes across courses, between their courses and UK SPEC, and between UK SPEC and the requirements for professional engineering). Overall levels of trust in UK-SpecIAL were very high. Students generally agreed that they trusted UK-SpecIAL because they could see the system's inferences, because of its clear relationship to UK SPEC, and because they could see relationships between courses.

Table 2. Use of OLMlets and UK-SpecIAL

Log Data: First Year Courses	Total	Mean	Median	Range
Questions attempted (n=86)	50745	577	428	4 - 2025
Viewing own model in OLMlets (n=84)	34793	400	316	1 - 1336
Viewing instructor expectations in OLMlets (n=54)	1053	19.5	14.5	1 - 120
Viewing UK-SpecIAL (n=79)	522	6.7	5	1 - 39

Table 3. Trust in OLMlets

Questionnaire Item: OLMlets	Mean	Median	Range
Understood learner model information	4.5	4	4-5
Learner model information was accurate	4.0	4	3-5
Helped identify knowledge (within first year courses)	4.5	5	3-5
Trust because can see system's inferences about oneself	3.8	4	1-5
Trust because can compare to instructor's expectations	4.2	5	1-5
Trust because can compare to other users	3.7	4	1-5
Overall trust in OLMlets learner model information	4.2	4	1-5

Table 4. Trust in UK-SpecIAL

Questionnaire Item: UK-SpecIAL	Mean	Median	Range
Understood learner model information	3.8	4	1-5
Learner model information was accurate	3.5	4	1-5
Helped identify knowledge (across courses)	3.9	4	1-5
Identify relationships: learning outcomes across courses	4.3	4	3-5
Identify relationships: courses/UK SPEC	4.3	4	2-5
Identify relationships: UK SPEC/professional engineering	4.2	4	2-5
Trust because can see system's inferences about oneself	3.9	4	2-5
Trust because relates to UK SPEC	4.0	4	1-5
Trust because demonstrates relationships between courses	3.9	4	1-5
Overall trust in UK-SpecIAL learner model information	4.4	5	3-5

The following are examples of typical open-ended comments about UK-SpecIAL:

- It is very important to know the uk-spec because it let me know many skills and required knowledge necessary to become a professional engineer. This allows

students to know and set their goals easily with this in place. Tendency of students not knowing why they are studying their modules will be greatly reduced.

- The point I find particularly important is how UK-SpecIAL relates to each module and then allows a student to see how the different modules fit together to provide a broad knowledge spectrum. This helps to prevent students seeing each module as a completely separate entity and allows them to gain a better overall view.
- It is exciting to find out how the learning outcomes from my course meet the requirements of employers which leads to a professional career in engineering.

4.3 Discussion

As an aim of our IOLMs is to encourage learner independence, we have not attempted to measure learning gains: we expect successful use of the systems to prompt study away from the environments, and students would not necessarily feel a need to verify their knowledge if they were confident in their independent study [18]. Nevertheless, students made extensive use of OLMlets in their first year courses, attempting well over 500 (mean), 400 (median) questions, and frequently accessed their individual learner models. Nearly two thirds also compared their knowledge to the instructor's expectations for the current stage of the course, in the courses in which this was available (mean 19.5, median 14.5 times). 92% of students accessed UK-SpecIAL during the term; 77% multiple times – even though only 80% of the users had been introduced to it. Students may also choose to release their learner model to others, which can be useful to those who like to work collaboratively or competitively. 49% released their models; 52% viewed peer models. Because the logs were anonymous, we do not know whether students used OLMlets in all courses in which it was available to them. However, there is sufficient use to suggest a simple IOLM can support learning over the duration of a set of courses, in students' own time: students would unlikely interact to this extent unless they perceive some benefit.

When a user can see the contents of their learner model, their beliefs about its accuracy and the extent to which they can interpret the representations, may affect their use of it. These issues relate to trust. Questionnaire responses suggest students did understand the representations in OLMlets in particular (also indicated by usage levels), considered them accurate, and useful in helping to identify their knowledge. The figures were a little lower for UK-SpecIAL. Students also claimed to trust both IOLMs. A key feature in engendering trust appears to be the ability to compare knowledge to instructor expectations. This allows users to not only determine their knowledge state, but also whether their current knowledge is 'acceptable'. Comparison of one's own model to peer models was also a feature contributing to trust. As only half the students used peer models, the existence of this information may be sufficient to contribute to user trust in this kind of system. That users can see relationships between courses, and to their future professions, also appears important. Students had a high level of trust in UK-SpecIAL despite needing to check progress with it only a few times in the term, and despite their lower confidence in its accuracy. Because of the infrequent need to refer to UK-SpecIAL, comments were also sought. The (typical) comments show users understood the purpose: e.g. they could explain its relationship to professional engineering, and relationships between their courses.

Based on the results, we suggest that simple IOLMs for use in and across courses can be found beneficial, and will be used in practice. As expected, use was high when models were assessed. However, in one course that did not assess the learner models, use was higher than in one of the courses that did assess them. Within a course an IOLM can help users pinpoint specific areas on which to focus their study; and an IOLM drawing together information from several courses can help users understand how components of their degree fit together. While UK-SpecIAL is specifically for engineering, the general approach could be applicable to a variety of disciplines.

Of course, the fact that questionnaire data came from a subset of users means that responses may not reflect the views of the whole group. However, we believe that there was sufficient use to warrant further study of use and trust of IOLMs in real settings. In particular, given the result for UK-SpecIAL, it seems important to investigate the relationship between perceived accuracy of the model and user trust.

5 Summary

This paper has presented OLMlets and UK-SpecIAL: independent open learner models to promote learner reflection and learner independence within courses, and a greater understanding of how courses fit together to build the 'bigger picture' of their degree and how this relates to their future professions. Usage logs showed that both systems were used by students, and questionnaire responses indicated that users trusted them. We therefore suggest that a similar approach may be useful in comparable university departments to promote metacognitive skills and independent learning by students outside lecture, lab and other scheduled sessions; and recommend investigation into whether the approach may generalise to other subjects.

Acknowledgments. UK-SpecIAL is funded by the UK Higher Education Academy Engineering Subject Centre (Ref: MPF 0806).

References

1. Robinson, S.L.: Trust and Breach of the Psychological Contract. Administrative Science Quarterly. 41, 574--599 (1996)
2. Lewis, J.D., Weigert, A.: Trust as Social Reality. J Social Forces. 63, 967--985 (1985)
3. Madsen, M., Gregor, S.: Measuring Human-Computer Trust. In: Gable, G., Viatle, M. (eds.) 11th Australasian Conference on Information Systems, 53 (2000)
4. Tanimoto, S.: Dimensions of Transparency in Open Learner Models. LeMoRe Workshop, Artificial Intelligence in Education 2005, pp. 100--106 (2005)
5. Bull, S., Kay, J.: Student Models that Invite the Learner In: The SMILI Open Learner Modelling Framework. Int. J. of Artificial Intelligence in Education. 17(2), 89--120 (2007)
6. Ahmad N., Bull, S.: Do Students Trust their Open Learner Models?. In: Nejdl, W., Kay, J., Pu, P., Herder, E. (eds.) AH 2008, LNCS, vol. 5149, pp. 255--258. Springer, Berlin (2008)
7. Ahmad, N., Bull, S.: Learner Trust in Learner Model Externalisations. Artificial Intelligence in Education 2009, IOS Press, Amsterdam (in press)

8. Land, SM, Hanaffin M,J.: Student-Centered Learning Environments: Foundations, Assumptions, and Implications. In: Proceedings of Selected Research and Development Presentations at the 1996 National Convention of the Association for Educational Communications and Technology (18th, Indianapolis, IN, 1996), pp. 394--400 (1996)
9. Higher Education Academy/Juwah et al. Enhancing Student Learning Through Effective Formative Feedback (2004), http://www.heacademy.ac.uk
10. Bull, S., Kay, J.: Metacognition and Open Learner Models, Workshop on Metacognition and Self-Regulated Learning in Educational Technologies. Int. Tutoring Systems (2008)
11. Kay, J.: Learner Know Thyself: Student Models to Give Learner Control and Responsibility. In: Halim, Z., Ottomann, T., Razak, Z. (eds.), Int. Conference on Computers in Education, AACE, pp. 17--24 (1997)
12. Boud, D.: Promoting Reflection in Learning: a Model. In: Boud, D., Keogh, R., Walker, D. (eds.) Reflection: Turning Experience into Learning. Kogan Page, London, Nichols Pub., New York, pp. 18--40 (1985)
13. Schon, D.: The Reflective Practitioner. Basic Books, USA (1983)
14. Dimitrova, V.: StyLE-OLM: Interactive Open Learner Modelling. Int. J. of Artificial Intelligence in Education. 13(1), 35--78 (2003)
15. Mabbott, A., Bull, S.: Alternative Views on Knowledge: Presentation of Open Learner Models. In Lester, J.C., Vicari, R.M., Paraguacu, F. (eds.), Intelligent Tutoring Systems: 7th International Conference, pp. 689--698. Springer-Verlag, Berlin Heidelberg, (2004)
16. Perez-Marin, D., Alfonseca, E., Rodriguez, P., Pascual-Neito, I.: A Study on the Possibility of Automatically Estimating the Confidence Value of Students' Knowledge in Generated Conceptual Models. J. of Computers. 2(5), 17--26 (2007)
17. Zapata-Rivera, J.D., Greer, J.E.: Interacting with Inspectable Bayesian Models. Int. J. of Artificial Intelligence in Education. 14, 127--163 (2004)
18. Bull, S., Mabbott, A., Gardner, P., Jackson, T., Lancaster, M., Quigley, S., Childs, P.A.: Supporting Interaction Preferences and Recognition of Misconceptions with Independent Open Learner Models. In: Nejdl, W., Kay, J., Pu, P., Herder, E. (eds.) AH 2008, LNCS, vol. 5149, pp. 62--72. Springer-Verlag, Heidelberg (2008)
19. Mitrovic, A., Martin, B.: Evaluating the Effect of Open Student Models on Self-Assessment. Int. J. of Artificial Intelligence in Education. 17(2), 121--144 (2007)
20. Weber, G., Brusilovsky, P.: ELM-ART: An Adaptive Versatile System for Web-Based Instruction, Int. J. of Artificial Intelligence in Education. 12, 351–384 (2001)
21. Engineering Council. UK Standard for Professional Engineering Competence, The Accreditation of Higher Education Programmes (2004), http://www.engc.org.uk/documents/Accreditation_HE_Progs.pdf
22. Biggs, J., Tang, C.: Teaching for Quality Learning at University, McGraw Hill, OUP, (2007)
23. Institution of Engineering and Technology (IET). Handbook of Learning Outcomes for BEng and MEng Degree Programmes (2006), http://www2.theiet.org
24. Jameson, A.: Adaptive Interfaces and Agents. In: Jacko, J.A., Sears, A. (eds.) Human-Computer Interaction Handbook, 2nd edn. Lawrence Erlbaum Publishers, Mahwa (2007)
25. Bull, S., Quigley, S., Mabbott, A.: Computer-Based Formative Assessment to Promote Reflection and Learner Autonomy. Engineering Education. 1, 8--18 (2006)
26. Buzzetto-More, N.A., Alade, A.J., Panda, D.: Using e-Learning to Drive a Student Learning Outcomes Based Assessment Program. In: Buzzetto-More, N.A. (ed.) Advanced Principles of Effective e-Learning. pp. 213--244. Informing Science Press, CA, (2007)
27. Maddocks, A.: EASIMAP: A Coherent Approach to the Assessment of Learning Outcomes on Engineering Degree Programmes. Engineering Education. 2(2), 26--32 (2007)
28. Avitabile, P., McKelliget, J., Van Zandt, T.: Interweaving Numerical Processing Techniques in Multisemester Projects. In: American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering, (2005)