

Students' interest in their misconceptions in first year electrical circuits and mathematics courses

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Abstract Based on deployment throughout a term, this paper suggests the potential of a computer-based approach to promote learner awareness of their knowledge states. We consider in particular the extent to which students are interested in finding out about their misconceptions in the context of independent study. It was found that many first year students held misconceptions in introductory electrical circuits and mathematics courses at some stage of their learning, and most viewed information about their misconceptions to assist them in identifying their problems. We suggest, therefore, that an approach of highlighting an individual's misconceptions can be found useful by students to help them recognise their knowledge, difficulties and misconceptions to support self-assessment and facilitate their identification of an appropriate focus of their efforts, to meet their learning needs.

Keywords misconceptions; electrical circuits; mathematics; engineering undergraduates; open learner model

The existence of learner problems and misconceptions is well-recognised at both pre-university and university level in electrical circuits^{1,2,3,4,5} and mathematics^{6,7,8,9}. As an example of difficulties students may have, consider the misconception that potential difference is caused by current flow (whereas in fact, the converse is true³). This refers to the relationship between potential difference and potential energy, and can be illustrated by making an analogy to gravitational potential energy: when water flows downhill it is because it is flowing from a region of higher gravitational potential energy to one of lower gravitational potential energy. The water does not create the gravitational field in which it flows! The inconsistency of the original conceptual framework causes confusion in later parts of students' education. For example, they may try to connect an ammeter in parallel instead of in series with a component. Difficulties in theoretical circuit analysis are likely to follow. For example, if

current flow is seen to cause potential difference, there is no rationale behind finding the open-circuit terminal voltage when calculating at Thevenin equivalent circuit. Alternatively, a student could deduce that there should be different, not equal, voltages across resistors connected in parallel.

Similarly, basic mathematics misconceptions can lead to later problems. For example, when adding two matrices, each corresponding term in each matrix is added to find the sum. When multiplying matrices there is a common misconception amongst less mathematically experienced students, that the same process can be followed: take each term in the two matrices and multiply them together to get the resultant corresponding term in the answer. The fact that most of the subsequent work in matrix algebra uses multiplication makes this problem an important one to overcome.

Explicit treatment of misconceptions has been recommended¹⁰ and survey results have suggested that many students would be interested in having access to information about their misconceptions as a means to better understand their learning¹¹. However, this kind of specific individualised information is often not available to students either because it is not revealed in tests or questioning, etc., or because students receive more general feedback about their performance, even if misconceptions are identified. In this paper we examine a computer-based method used to identify misconceptions, focusing on first year introductory electrical circuits and mathematics modules since these are fundamental to students' degrees, and difficulties here can continue into later courses. We describe the extent to which students reviewed their misconceptions in their 'open learner model', as a means of determining their interest in their misconceptions as a starting point for their independent investigation of their difficulties.

Using open learner models to understand learning

In this section we first introduce the notion of open learner modelling and suggest how open learner models can be used to identify the existence of misconceptions to help students understand their knowledge states, in order that they may undertake appropriate action to further their learning. We then present the OLMlets open learner model.

Open learner models

An effective means of diagnosing learner misconceptions is through learner modelling. A learner model is a computer-based representation of a learner's current understanding, which may include data relating to knowledge levels, concepts known, difficulties and misconceptions. Typically the learner

model is inferred according to the user's answers to questions or attempts at problem solving, and is dynamically updated to reflect current beliefs (i.e. it is not simply an overall performance score or a breakdown of marks). The usual purpose of a learner model is to allow a computer-based educational interaction to be personalised to the student's learning requirements according to information it infers about their present knowledge state, held in the learner model (e.g. selection or generation of individualised information, explanations, tutorials, feedback, exercises).

The learner does not usually have access to their learner model, as its primary purpose is to enable an interaction to be automatically adapted to their needs, as stated above. However, it has been suggested that the contents of the learner model can be opened to the learner it represents, in order to prompt students to reflect on their developing knowledge and to promote formative assessment¹². This use of open learner models is in line with the U.K. Higher Education Academy's recommendation of encouraging effective self-assessment and reflection, and feedback on learning¹³.

Most open learner models are part of a full adaptive learning environment, as described above. However, open learner models may also be used independently of a full system - i.e. the system constructs the model and provides access to it, but does not closely guide the user with inferred suitable teaching strategies. The aim of such 'independent open learner models' is to encourage learner autonomy, giving the learner greater responsibility for decisions in their learning. By inspecting representations of their knowledge, difficulties and misconceptions in their open learner model, students can identify where they most need to invest effort, and then independently undertake appropriate work accordingly. The independent open learner model approach is used in the OLMlets open learner model introduced below.

The OLMlets open learner model

OLMlets is designed for any course for which appropriate multiple choice questions can be defined. These are input by the course instructor through a separate instructor interface¹². While multiple choice questions are sometimes criticised for testing recall, they can also be designed to assess higher levels of cognition¹⁴, and this is our main interest here. It is the learner's *understanding* that we focus on, in particular, their misconceptions.

As OLMlets is subject-independent it uses simple learner modelling techniques in order to allow it to be easily deployed in different courses. For example, it does not require detailed specification of

concepts or relationships between concepts to be defined by instructors for each instance of use, as would be necessary for complex open learner model presentations such as concept maps^{15,16} or hierarchical tree structures^{15,17}. The OLMlets learner model represents current knowledge levels and misconceptions, and is constructed according to a student's most recent five responses to multiple choice questions for each topic, with each having a value between 0 and 1. Topics can be broad or narrow, as appropriate to the context of use. A knowledge level approaching 1 for a topic indicates a good understanding, and a value close to 1 for a specific misconception indicates a high probability that the learner holds that misconception. Heavier weighting is placed on the most recent of the last five attempts (the weighting increases by 0.3 for each successive response). So, for example, if a student answered their last 5 questions on a topic in a sequence of *incorrect-correct-correct-incorrect-correct*, their learner model will show a lower level of understanding than if they responded *incorrect-incorrect-correct-correct-correct*. If they had very many incorrect responses followed by three correct responses, their learner model would be the same as in the latter example because the weighting on recent interaction ensures that the model remains representative of current knowledge. Similarly, the more recently and frequently a misconception was revealed, the greater the weighting it has in the learner model. An 'unsure' option is provided for each question to improve the accuracy of the modelling: as students do not have to guess if they are not confident of an answer, 'unsure' responses are modelled as undefined difficulties/lack of knowledge.

Because of the simplicity of the learner modelling in OLMlets, the presentation of the OLMlets learner model is necessarily also simple. The most common form of simple open learner model is the skill meter^{18,19}. OLMlets uses skill meters and also four additional learner model views to accommodate learner preferences. Text descriptions of misconceptions are available in each view. (For example, 'you may believe that resistance is reactive'; 'you may believe that, when adding matrices, the individual terms within a matrix are added together'.) Fig. 1 shows examples of the three generally most frequently used learner model views, for a learner at a stage of having misconceptions (shaded red – dark in Fig. 1) and general difficulties (shaded grey/light) in most topics. Knowledge level is indicated by the initial (green/medium shading) colour block in the skill meter on the top left of Fig. 1, and the final block in the other graphical view at the bottom left of Fig. 1. The table view shows knowledge level in ranked order. (Note that this is an extreme example showing many misconceptions, selected for the purpose of illustration.)



Figure 1: Three views of the OLMlets open learner model

OLMlets is a practice environment - it is an independent open learner model which, as explained above, does not itself perform tutoring and so differs from traditional adaptive learning environments. Its aim is to help learners identify their learning needs for themselves (by presenting them with their learner model), in order that they may then direct their efforts as required - i.e. it aims to facilitate learner independence and formative assessment. Thus the learner retains the responsibility for their learning. They may prefer to answer only a few questions at a time to identify problems to follow up in independent work, or consult materials while using OLMlets, aiming to resolve their difficulties during a session. OLMlets has been found to support several such usage patterns²⁰. An advantage of the

learner modelling approach, as described above, is that the focus always remains on *current understanding*, because the learner model representation is weighted on the most recent responses and dynamically updated as the user interacts further. Students are not informed precisely which questions they answered correctly or incorrectly in order to focus their attention on their *knowledge* and the modelled *concepts*, rather than on the accuracy of their answers to specific questions.

It should be noted that it is not expected that all students should use OLMlets - for example, those who are proficient in self-evaluation, or who have other successful learning strategies in place, may benefit less. We offer OLMlets for those who find it a useful additional learning resource to facilitate identification of their needs.

In the following section we present results of use of OLMlets in two introductory first year courses, considering in particular, students' interest in their misconceptions.

Using OLMlets to understand learning

We here focus on first year introductory electrical circuits and mathematics courses, as these are fundamental to students' degrees, and unresolved misconceptions at this stage can persist into more advanced levels. As stated above, misconceptions in subjects such as these have been previously identified. Given the existing literature, we do not attempt to provide detailed misconceptions descriptions in this paper. Rather, the primary aim is to discover the extent of student misconceptions and the level of student interest in their misconceptions as a means to better understand and focus their learning.

The questions used in the two OLMlets courses were designed to elicit the misconceptions most commonly demonstrated by our students in initial diagnostic testing, laboratory exercises, tutorial questions and examinations. For example, a relatively straightforward question in the electrical circuits course asking students to complete the phrase 'The direction of the mesh currents in mesh analysis...' with one of the following: (a) must be clockwise; (b) is traditionally chosen to be clockwise; (c) must be anticlockwise; (d) is traditionally chosen to be anticlockwise; (e) must be into the positive terminal of all voltage sources; (f) must be into the negative terminal of all voltage sources; (g) unsure, allows OLMlets to elicit evidence to contribute towards the identification of a general misconception that the direction of mesh currents matters in mesh analysis from options 'a', 'c', 'e' and 'f' (also showing their specific belief). Students may not realise that mesh currents are a modelling construct from which the

real parameters of the circuit are later deduced. In fact, they simply need to assign a direction to the mesh currents and be consistent with it, and it is purely tradition and to avoid confusion that the direction is chosen to be clockwise. Only once this correct decision has been made, can students go on to apply other fundamental concepts to write down the equations or matrices describing the circuit model which they can then solve using mathematical concepts. A more complex example relating to the misconception 'positive ϕ means lag' is addressed (amongst others) by the question 'Consider the sine wave $V_0\sin(\omega t)$. A wave which lags this sine wave by a phase angle ϕ may be written as...' where the option ' $V_0\sin(\omega t + \phi)$ ' reflects difficulties students have in reading equations and relating them to, for example, the waveform seen on an oscilloscope or drawn out in a graph. Such a misconception will lead to problems later on, when students have to draw phasor diagrams and analyse the response of reactive circuits.

Open learner models have been found able to foster improvements in knowledge²¹ and self-assessment skills¹⁸ of adult learners. Given that OLMlets is designed to raise learner awareness of their knowledge state in order that they may make informed decisions about their learning, we do not here investigate learning gains. A lower level of knowledge in OLMlets in a real use context might, for example, represent a student who identified their problems and then overcame them independently, without feeling a need to return to OLMlets to confirm their improved understanding. We here assume that students will use the environment to the extent that they consider it helpful, and will not use it if they perceive little benefit. (Perhaps one of the strongest indicators of the utility of OLMlets is that during a Staff-Student Consultative Committee meeting, the First Year Representative reported student requests for OLMlets to be made available in more modules. This was an unsolicited comment - i.e. we had not asked about reactions to OLMlets.)

In this paper we are interested particularly in the extent of student misconceptions, and the extent to which students view information about their misconceptions as an indication of their interest in their misconceptions as a starting point for their independent study.

Participants, materials and methods

Participants were 49 first year students registered on degrees in the School of Electronic, Electrical and Computer Engineering at the University of Birmingham: 18 taking the mathematics module and 31 taking the electrical circuits course.

The mathematics module is designed primarily to raise the mathematical skills of students admitted onto a degree for which an A Level in maths is not a requirement. These include the 'Computer Interactive Systems' degree which covers the human end of interactive systems through courses such as the first year 'Introduction to Human Performance', as well as more traditional engineering modules such as the first year 'Digital Logic and Microprocessor Systems'. Around two thirds of these students do not have A Level mathematics.

Those taking the electrical circuits module have a more traditional background for study in an engineering department, pursuing degrees such as Electronic and Electrical Engineering, taking some of the same modules as the above students (e.g. 'Digital Logic and Microprocessor Systems'), but also modules such as the first year 'Electrical Energy Systems and Control'.

OLMlets was offered throughout a term, alongside the electrical circuits and mathematics courses. It was recommended as a practice environment that could help raise students' awareness of any difficulties, so that they could work on these during the modules. The OLMlets logs were reviewed to determine the misconceptions held by students, and the extent to which they viewed the descriptions of their misconceptions. All student data was anonymised.

Results

The electrical circuits module had 31 students trying OLMlets - 94% of those registered for the course; and the mathematics module had 18 OLMlets users - 120% of students who took the course (i.e. there were more students answering the maths questions than were actually taking the module). In the above figures we have excluded the small number of students who officially or implicitly withdrew from the modules before the end of the year (by implicitly we mean, for example, that they did not attend the compulsory laboratory sessions and were not present for the examination).

In total, 16 misconceptions were identified in the maths module, and 44 in the electrical circuits module. Tables 1 and 2 show the most common incorrect beliefs identified. The second column shows misconceptions held at some stage by between one fifth and one third of learners; misconceptions held by one third or more learners are identified in the final column. Table 1 shows the common inaccurate beliefs identified in the maths module (N=10), and Table 2, the electrical circuits module (N=21).

Table 1. Incorrect beliefs in mathematics course

Misconception / incorrect belief	1/5+	1/3+
A negative number multiplied by a positive number results in a positive number	X	
Factored expressions can include squared or higher order terms (unfinished)		X
Multiplying two negative numbers yields a negative result	X	
When simplifying, same order terms are not subtracted or added (unfinished)	X	
Denominators are added when adding fractions		X
When adding matrices, the individual terms within a matrix are added together	X	
Multiplying matrices is like adding (where each term is obtained by multiplying the corresponding terms in the two matrices)		X
When evaluating the inverse of a matrix, the elements in the original matrix are swapped around		X
Integrating $\cos(x)$ gives $-\sin(x)$ and/or integrating $\sin(x)$ gives $\cos(x)$		X
In a definite integral, the limits are not substituted after the integration	X	

Table 2. Incorrect beliefs in electrical circuits course

Misconception / incorrect belief	1/5+	1/3+
Electrons carry positive charge	X	
Current is related to potential energy	X	
Voltage and current are the same	X	
The dual of a parallel resistance is an open circuit	X	
The dual of a circuit can be created by finding the dual of one component	X	
Voltage and current generators are identical		X
The direction of mesh currents matters in mesh analysis	X	
Voltage across parallel branches is different for each branch	X	
Current can change within a branch		X
Number of nodes equals number of equations in nodal analysis	X	
$I = VR$		X
'Sinusoidal' means the same as 'sine'	X	
Cosine of angles greater than $\pi/2$ but less than $3\pi/2$ is positive		X
$\cos(0) = 0$		X
Angular frequency is measured in units of degrees		X
Positive ϕ means lag		X
Phasor notation requires the negative of the phase angle	X	
$X = \omega C$		X
Current leads voltage in an inductor	X	
Resistance does not enter phasor diagram	X	
Resistance is reactive		X

Tables 1 and 2 show that in both courses there were a range of misconceptions held by students at some point. (Examination of the system logs revealed that students were often using the 'unsure' option to indicate that they did not know an answer. It is probable, therefore, that in most cases selection of a misconceptions distractor did indeed indicate the student held that misconception, rather than that they were guessing.)

As shown in Table 3, most students held misconceptions at some stage. Most of these also viewed the statements of their misconceptions, particularly in the electrical circuits module.

Table 3. Inspections of misconception descriptions

Course	Percent holding misconceptions at some point	Percent viewing misconceptions (of those holding misconceptions)
Electrical circuits	97% (30 students)	93% (28 students)
Mathematics	94% (17 students)	71% (12 students)

The following student comments illustrate how they typically used the information about their misconceptions:

- “The misconceptions feedback was useful - I went back to the notes and the books, revised the material and then got the questions right.”
- “It will explain to me what the misconceptions are which I think really good to know. When I realized that I have misconceptions, obviously I will refer back to the lecture notes and try to figure out why OLMlets told me that I have misconceptions.”
- OLMlets can potentially become the number one source for students to analyse how far you have done revision, how deep you have dig in that module and in return, you will be told what to do to improve yourself.

Discussion

Most students taking the two modules tried OLMlets. As there were more users of the maths OLMlets questions than were actually registered for the module, we hypothesise that these additional users were students outside the course attempting questions because they recognised they had weaknesses in their understanding of the maths covered in the module. For example, they may have been second year students who found that they lacked adequate recollection of first year material in order to do well in a

second year course; or first year students not taking the module, but who found their mathematical skills were weak in comparison to their peers. Anonymised data prohibits further investigation of this issue. However, regardless of the reason, this usage by students who were not registered for the module suggests that OLMlets can support students who identify a need to review their knowledge of an area that is assumed to be already known. This use is likely to have been by students who had already found OLMlets helpful in other courses (this was the first time OLMlets was deployed in this module, therefore the additional users had not previously used it for this course).

Many students held misconceptions. While the proportion of students with misconceptions appears quite high, and some of the misconceptions are at a basic level, it should be remembered that these figures refer to students who held the misconception *at some point* during their learning. In some cases this would have been at the start of the course, and both modules were first year introductory modules. Furthermore, the majority of students taking the mathematics module did not have A Level maths. As stated previously, there has been much work on student misconceptions in these areas, and so the fact that we were able to identify many misconceptions was not unexpected. Moreover, in a consideration of the large decline in home students studying electronic and electrical engineering, the U.K. Engineering and Technology Board refers to the suggestion of some, of a growing gap between the content of maths and physics A Levels and the requirements of electronic engineering courses²². It is perhaps not surprising, therefore, that some students found aspects of their course challenging – not only those in our sample who do not have A Level mathematics.

Nearly all those with misconceptions in the electrical circuits course, and two thirds of those in the maths course, reviewed the description(s) of their misconception(s). While there has been much interest in defining student misconceptions and identifying the underlying causes of misconceptions, and how this information might be used in teaching, there has been little investigation of the extent to which students themselves may be interested in understanding their misconceptions. It is, of course, the nature of misconceptions, that students do not realise they hold them. We have shown here that many students will indeed consult descriptions of their specific misconceptions if these are available, thereby gaining information about their beliefs that would otherwise not be revealed to them. However, we do not claim that pointing out a misconception to a student (as in OLMlets), will necessarily be sufficient for them to understand the reason that their belief is incorrect. Our aim is to help students identify that they have such difficulties in order that they may take steps to overcome any problems - i.e. we aim to

encourage *learner autonomy* or *learner independence* (this may, of course, include asking the instructor for clarification where there is confusion). Student comments indicate that they are indeed using OLMlets to facilitate independent learning.

Given the prevalence of misconceptions in mathematics and electrical circuits as identified in the literature, and student interest in misconceptions as found in our study, we recommend use of an open learner model or some other approach to identify and confront students with their misconceptions, to help them better understand their knowledge state and plan their learning accordingly.

Summary

This paper has described use of OLMlets by first year electronic, electrical and computer engineering students alongside a mathematics and an electrical circuits course. Most students had misconceptions during their learning, and a range of misconceptions were identified. Most learners viewed descriptions of their misconceptions. We therefore suggest that a simple open learner model 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 where they lack accurate self-assessment skills, or where they like to obtain confirmation of their understanding.

References

- 1 P. Brna, 'Confronting Misconceptions in the Domain of Simple Electrical Circuits', *Instructional Science*, **17(1)**, (1988), pp. 29-55.
- 2 K-E. Chang, S-H. Liu & S.W. Chen, 'A Testing System for Diagnosing Misconceptions in DC Electric Circuits', *Computers and Education* **31**, (1998), pp. 195-210.
- 3 R. Cohen, B. Eylon & U. Ganiel, 'Potential Difference and Current in Simple Electric Circuits: A study of Students' Concepts', *American Journal of Physics* **51(5)**, (1983), pp. 407-412.
- 4 P.V. Engelhardt & R.J. Beichner, 'Students' Understanding of Direct Current Resistive Electrical Circuits', *American Journal of Physics* **72(1)**, (2004), pp. 98-115.
- 5 R. Nasr, S.R. Hall & P. Garik, 'Student Misconceptions in Signals and Systems and their Origins', *33rd ASEE/IEEE Frontiers in Education Conference*, Boulder, CO, (2003), pp. 23-28.
- 6 J. Garfield & A. Ahlgren, 'Difficulties in Learning Basic Concepts in Probability and Statistics: Implications for Research', *Journal for Research in Mathematics Education* **19(1)**, (1988), pp. 44-63.
- 7 I.R.Gibson, F.H. Goldman & M. Grinfeld, 'Mathematics at the School-University Interface in Scotland', *Research Report Number 7: 2005*, (Department of Mathematics, University of Strathclyde, 2005).

- 8 A.O.Graeber, D. Tirosh & R. Glover, 'Preservice Teachers' Misconceptions in Solving Verbal Problems in Multiplication and Division', *Journal for Research in Mathematics Education* **20(1)**, (1989), pp. 95-102.
- 9 L.S. Hirsch & A.M. O'Donnell, 'Representativeness in Statistical Reasoning: Identifying and Assessing Misconceptions', *Journal of Statistics Education* **9(2)**, (2001), <http://www.amstat.org/publications/jse/v9n2/hirsch.html>.
- 10 D.A. Muller, J. Bewes, M.D. Sharma & P. Reimann, 'Saying the Wrong Thing: Improving Learning with Multimedia by Including Misconceptions', *Journal of Computer Assisted Learning* **24**, (2007), pp. 144-155.
- 11 S. Bull, 'Supporting Learning with Open Learner Models', *Proceedings of 4th Hellenic Conference on Information and Communication Technologies in Education*, Athens, (2004), pp. 47-61.
- 12 S. Bull, S. Quigley & A. Mabbott, 'Computer-Based Formative Assessment to Promote Reflection and Learner Autonomy', *Engineering Education: Journal of the Higher Education Academy Engineering Subject Centre* **1(1)**, (2006), pp. 8-18.
- 13 Higher Education Academy/Jawah et al., 'Enhancing Student Learning Through Effective Formative Feedback', (Higher Education Academy, 2004), [http://www.heacademy.ac.uk/assets/York/documents/resources/resource database/id353_senlef_guide.pdf](http://www.heacademy.ac.uk/assets/York/documents/resources/resource%20database/id353_senlef_guide.pdf).
- 14 K. Woodford & P. Bancroft, 'Multiple Choice Questions Not Considered Harmful', *Proceedings of the 7th Australasian Conference on Computing Education (volume 42)*, (ACM International Conference Proceedings Series Vol. 106, 2005), pp. 109-116.
- 15 A. Mabbott & S. Bull, 'Alternative Views on Knowledge: Presentation of Open Learner Models', in J.C. Lester, R.M. Vicari & F. Paraguacu (eds.), *Intelligent Tutoring Systems: 7th International Conference*, Springer-Verlag, (Berlin Heidelberg, 2004), pp. 689-698.
- 16 D. Perez-Marin, I. Pascual-Nieto, E. Alfonso & P. Rodriguez, 'Automatically Generated Inspectable Learning Models for Students', in R. Luckin, K.R. Koedinger & J. Greer (eds.), *Artificial Intelligence in Education*, (IOS Press, Amsterdam, 2007), pp. 632-634.
- 17 J. Kay, 'Learner Know Thyself: Student Models to Give Learner Control and Responsibility', *Proceedings of International Conference on Computers in Education*, (Association for the Advancement of Computers in Education, 1997), pp. 17-24.
- 18 A. Mitrovic & B. Martin, 'Evaluating the Effect of Open Student Models on Self-Assessment', *International Journal of Artificial Intelligence in Education* **17(2)**, (2007), pp. 121-144.
- 19 G. Weber, & P. Brusilovsky, 'ELM-ART: An Adaptive Versatile System for Web-based Instruction', *International Journal of Artificial Intelligence in Education* **12**, (2001), pp. 351-384.
- 20 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 W.

- Neijdl, J. Kay, P. Pu & E. Herder (eds), *Adaptive Hypermedia and Adaptive Web-Based Systems*, (Springer-Verlag, Berlin Heidelberg, 2008), pp. 62-72.
- 21 Shahrour, G. & Bull, S. Does 'Notice' Prompt Noticing? Raising Awareness in Language Learning with an Open Learner Model, in W. Neijdl, J. Kay, P. Pu & E. Herder (eds), *Adaptive Hypermedia and Adaptive Web-Based Systems*, (Springer-Verlag, Berlin Heidelberg, 2008), pp. 173-182.
- 22 Engineering and Technology Board, 'Engineering UK 2006', Research Report, (2006), http://www.etechnology.co.uk/_db/_documents/Engineering_UK_2006.pdf.