Seeding Enquiry-Based Learning in Electrical and Electronic Engineering:
Case Study 2 – Robotics

Norman J. Powell[1], Alasdair Renfrew [2], William S. Truscott [3], Peter J. Hicks [4], Brian Canavan [5]

Abstract - **Enquiry-Based Learning (EBL) was developed in the third-year module Robotics. Problem-Based Learning (PBL) is an instance of EBL, where the students' enquiry into a topic is triggered by an initial scenario. A PBL scenario was introduced towards the end of this module, where the students are asked to act as consultants engaged in a systems integration activity for a selected industrial automation process. The scenario requires the selection and integration of automated material handling components, including conveyer belts, robots and sensors. Being at the end of the module, this activity provides an opportunity for the integration of earlier module content into the activity, as well as the finding, analysis and synthesis of new information. Key decisions in the design of the scenario, consideration of the learning environment and the form of assessment are described, emphasising flexibility in approach and sensitivity to the context of this development.**

This development is in the second year of its delivery. The results of an integrative evaluation, drawing on questionnaires, participant observation and student focus groups, will be presented. The experiences and creativity of the groups of students who have worked through this scenario will be presented, highlighting the impact of internal and external factors.

Index Terms – Electronic Engineering, Enquiry-Based Learning (EBL), Problem-Based Learning (PBL), Robotics.

INTRODUCTION

The development of professional and personal skills in engineering students is becoming increasingly important. A recent survey of employers, conducted by the IET (Institution for Engineering and Technology) [1], highlighted a mismatch between the skills required by electronic engineers and the skills that graduates possessed. This finding is in line with similar studies and engineering education reviews in both America and Australia [2]. PBL is an instance of EBL [3], where the students' enquiry into a topic is triggered by an initial problem or scenario. The students following in this enquiry engage in the subject matter at a much deeper level, whilst gaining professional, personal and life-long learning skills in a process integrated with their core subject learning [4].

This paper and its companion paper (Case Study 1 – Optoelectronics) report on some of the teaching and learning developments that arose at the University of Manchester, from a collaborative PBL initiative with University College London and the University of Bristol, supported by the IET [1] and HEFCE (Higher Education Funding Council for England). In Manchester, PBL has been introduced into three third-year units, in the areas of VLSI design [5], Optoelectronics and Robotics, and also as part of the second-year tutorial system as a preparation for a team project [6].

This paper describes the context of the module, and the *implementation* of a PBL exercise into it. It then describes the *evaluation* of the PBL exercise drawing out the experiences and reactions of the students involved.

IMPLEMENTATION

Context

Robotics is a core, 10-credit, third-year, second-semester module delivered through lectures and problem-solving tutorials delivered towards the end of the module as preparation for the examination. The module also includes two related laboratory sessions. One laboratory introduces the programming of an industrial six-axis robot. The other laboratory introduces the use of *Workspace* [7], a three-dimensional computer-aided design (CAD) program used to design and simulate a robotic work cell. The contact time for the module is two 50-minute sessions per week, excluding laboratories.

This module has recently been expanded from being a 5-credit module. The inclusion of a systems integration activity and the *Workspace* laboratory formed part of that expansion.

A summative exam represents the 80% of the module delivered through lectures. The coursework component of the module is made up by 10% from the laboratories and 10% from the systems integration PBL activity.

Rationale

The systems integration of the components that make up a robotic work cell is an important industrial skill in robotics. Mechatronic graduates, entering the robotics industry, are more likely to be involved in the design and integration of

---

[1] Norman J. Powell, Centre for Excellence in Enquiry-Based Learning, University of Manchester, United Kingdom, norman.powell@manchester.ac.uk
[2] Alasdair Renfrew, School of Electronics and Electrical Engineering, University of Manchester, United Kingdom, a.peaker@manchester.ac.uk
[3] William S. Truscott, School of Electronics and Electrical Engineering, University of Manchester, United Kingdom, w.truscott@manchester.ac.uk
[4] Peter J. Hicks, School of Electronics and Electrical Engineering, University of Manchester, United Kingdom, peter.hicks@manchester.ac.uk
[5] Brian Canavan, Robert Clark Centre for Technological Education, University of Glasgow, United Kingdom, b.canavan@elec.gla.ac.uk

automated components, including existing robots to automate an industrial process, rather than be involved in the design of new robots, especially in the context of the United Kingdom or Europe. Systems integration is a skill, requiring the shifting of emphasis to the level of the whole system from the individual components that make it up. Being a skill, it is something best developed through practise rather than being taught. Consequently, it lends itself naturally to a student-centred collaborative activity, such as PBL.

Like PBL in the medical context, it is the process that the students engage with in addressing the problem or scenario that is an important part of the learning. In the medical context, the process of assessing symptoms, researching existing knowledge to: understand the symptoms; to assist in deciding the diagnosis; and decide on a course of action, is central to learning how to be a practicing doctor. In this context, it is the process of: analysing the system requirements of the scenario; researching and selecting the appropriate components; and assessing the performance of the system designed, that is the key to the learning systems integration. Exposure to the possible particular system components that they must select from is a desirable secondary component of the learning, which arises naturally out of the activity.

Scenario

The students are asked to act as consultants engaged in a systems integration activity for a selected industrial automation process. The scenario requires the selection and integration of automated material handling components, including conveyer belts, robots and sensors.

Over the two years of delivery, the industrial automation process scenario has been changed and it is anticipated that different scenarios will be introduced in subsequent years.

In 2005-06, the scenario was based around Wigan Weight Watchers, who required a system to palletise their watercress soup cans. The cans arrived on a smart-belt, an item that the students had to research, and boxes arrived and were removed on a second conveyer-belt. The system was further complicated by the requirement that the each can had to have its bar code read before it was palletised. An optional extension that some groups considered was to include a rejection route for cans that had the wrong bar code.

In 2006-07, the scenario was based around Wigan Waggon Works Wheels Warehouse, who needed a system to spray a rust-proof paint onto their wheels. This scenario was complicated by each wheel requiring three or four coats of paint, depending on the spraying method. In addition each coat required an hours drying time. A further complication was that half the wheels required an additional coat of cosmetic paint applied to one side.

In both scenarios, an estimation of the cycle time of the system, the time to complete one cycle of action, and hence the capacity of the systems, was required. Cost was not considered an issue in these scenarios, since determining this for all components of the systems was impractical.

Timing

This topic fits naturally towards of the end of the module, after the students have been exposed to robots and studied them in detail, and most have had opportunity to attend the laboratories. More critically, the PBL activity should occur after the two industrial talks, described below.

In 2005-06, the PBL exercise was scheduled to take place after the Easter vacation, in the last teaching weeks of the semester. However, this was very close to the submission date for the third-year projects and so was a very pressured time for the students. Student feedback indicated that it should be scheduled earlier in the semester.

In 2006-07, the PBL exercise was scheduled to take place in the three weeks before the Easter vacation, moving revision lectures and tutorials to after Easter. This arrangement was much better received.

Resources

Students received a briefing for the scenario, which included a brief description of the process that required automation, a plan of the workspace, with the location and dimensions of existing components and the dimensions of any workpieces: soup cans or wagon wheels.

It was anticipated that the majority of resources would be accessed via the Internet, through searching manufacturers' websites. Some useful websites were suggested during the first meeting as a starting point for their enquiry.

Another resource, put in place prior to the commencement of the PBL activity, was two industrial lectures, one from a systems integration company and another from an industrial robot supplier company. Both of these lectures provided examples of robotic systems integration, with pictures and video clips of real automated processes in action. Some of the design decisions and complications associated with the systems were described. The second lecture was very interactive: the speaker outlined a number of scenarios in turn, then provided a selection of possible robots, grippers and sensors for the application. He then asked the class to choose one of the options and gave feedback on suitability of that selection and through this process converged on an optimal solution, finishing with a video clip of that solution in action. These lectures provided: a change of pace from regular lectures; a model the process of systems integration through concrete examples; a bank of solution ideas to draw from; and visualisations of a variety of systems.

Learning Environment

This module was scheduled to take place in a flat lecture theatre. Groups facilitated by the lecturer met in his office. Groups facilitated by the assistant facilitator met around tables in the flat lecture theatre.

Group Selection

Since this was a core module for the Mechatronics programme, the number of students was known prior to the course. The lecture was also familiar with the students so was able to select groups in advance of the activity, according to following criteria:

- groups were tutor selected, not student selected;
- group numbers were kept small, four to five students;
- abilities of the group members were mixed;

- female students where placed in a group with another female student;
- in 2005-06, students who had done an optional *Variable Speed Drives* module, which was considered to provide beneficial background information, were divided among the groups where possible: in 2006-07 this became a core module;
- students who tended to work together were split up, to avoid sub-groups forming within the groups.

Process

During the team meetings, the students in their groups:

- discussed their understanding of the scenario;
- shared their current knowledge and ideas on the topics involved;
- made decisions on how to address the scenario;
- identified what specific topics, or learning objectives, they needed to research in order to progress their enquiry;
- allocated who was going to investigate which topics;
- made arrangements for keeping in contact with each other between the scheduled facilitated sessions.

Between the team meetings the students would conduct their individual research on the topics allocated. The next team meeting would then begin with the students sharing the findings of their individual research with the group and discussing how their findings affect their perceptions of the scenario. Then the process of identifying learning outcomes and planning their group research was repeated and refined.

Facilitation

The lecture slots were divided up into thirty-minute facilitated meetings, thirty-five minutes for the first week. Each group was allocated one of these slots for each of the three weeks of the PBL activity. Each group was expected to meet for an unfacilitated meeting between the sessions and forward minutes of this meeting to the facilitator. This usually occurred in the other lecture slot. In practice the meetings fitted well into these time slots.

Due to the restricted times of these meetings, the facilitator tended to take a more directive role: chairing the meeting and acting as someone for the group to report to. This is balanced by the fact that the meetings where most of the discussions and decisions take place were the unfacilitated meetings.

The first meeting was used to distribute the scenario and check the groups understanding of it by asking them to describe it back in their own words. The group then began to break the task down, considering what components would be needed for the system. During this phase of the meeting any clarification or additional information and helpful websites would be introduced. The meeting finished with the group deciding on clear objectives. The division of tasks, exchange of details and arrangements for the unfacilitated meeting usually took place immediately after this meeting as the group left together.

The second meeting was used to check the groups' progress against their stated objectives and as an opportunity for the group to report on how far they had got with designing their system. The facilitator would have a 'check-list' of expected system components and considerations that groups were expected to have covered. This would be used to draw out the specific details of the system that the groups were designing and provide a check that the group had considered all the aspects expected.

The final meeting again checked the group's progress against their objectives and ensure all the system components were covered. The systems were almost finalised by this stage and considerations about the final reporting of the system in a group poster were made.

Throughout the students were encouraged to be creative in their solutions and to make any assumptions about the scenario that they needed to, as long as they were stated on the final poster.

Assessment

The PBL activity was assessed through a group poster. A single group mark was given to the poster that was then awarded to all the group members. This seemed appropriate for the level of credit that the activity was attributed.

Provision was made to deal with group members who were not attending or participating to the group process through a yellow and red card system. If an individual was not contributing or had missed a meeting, the facilitator could issue a yellow warning card. If the individual did not amend their behaviour then a red card was issued, which meant the individual was removed from the group and was required to submit an individual poster to gain any credit from this exercise.

The posters were put on display over lunchtime and third and first year Mechatronic students were invited to the view the posters. After this the posters were marked out of 10, based on whether the expected components of the system had adequately been cover on the poster (5.5/10) and the degree of creativity in the solution (4.5/10). The posters were marked independently by the lecturer and the assistant facilitator; the final marks were then agreed.

In addition to the poster, one of the exam questions, that students could select to answer, covered the topic of systems integration and would be best answered by describing the process of systems integration followed in this activity.

Delivery

The PBL exercise was first delivered in the second semester of 2005-06 to 6 groups of 4 and 5 students, 29 students in total. It was repeated in the second semester of 2006-07 to 4 groups of 4 students. Both cohorts contained a mixture of both home and foreign students.

EVALUATION

Methodology

An integrative evaluation [8] was conducted, drawing on questionnaires, assessment, participant observation, student focus groups and the reflections of staff, where the focus is on understanding the experience of the students engaged on the PBL exercise. The questionnaire data was collected for the first year of delivery, observations and focus groups were conducted for both years of delivery.

Questionnaires

There were a moderate number of students involved in this activity (29 students) and the response rates were fair (52%-72%), so the results can be taken as representative and a fair indication of these students' responses.

The Study Process Questionnaire [9] measures the students' approaches to learning, whether deep or surface. On average the cohort came out as having a Deep Learning Attitude of 26.3 and a Surface Learning Attitude of 23.1 (15 responses, 52%). This is not significantly different from other second and third year groups ($F(3,62)=0.12$, $p=0.95$ & $F(3,62)=0.82$, $p=0.49$ for deep and surface respectively).

Confidence Logs [8] measuring the students' confidence on a five-point Likert scale against the intended learning outcomes for the PBL were collected pre and post the PBL exercise. The results are summarised in Table I for paired comparisons. The results show highly significant increases in confidence for three of the four learning outcomes and a smaller but significant increase in confidence for the other (robot interfacing). Since only 12 students (41%) submitted responses that could be paired, this may not be representative. Table II shows the results of an independent comparison for all the submitted responses. These results show a similar if diluted pattern, with learning outcome 1 (robot criteria) and 3 (robot work envelope) remaining significant.

TABLE I
PAIRED CHANGE IN CONFIDENCE (1-5) FOR LEARNING OUTCOMES

Learning Outcomes		Change in Confidence	Standard Deviation	Sig. *p*
1	The criteria for application of a robot to a specific task	0.92	0.79	** 0.002
2	How robots are interfaced	0.33	0.49	* 0.039
3	The limitations of a robot work envelope	0.83	0.72	** 0.002
4	The significance of cycle time	0.83	0.83	** 0.005
Average for all Learning Outcomes		0.73	0.54	** 0.001

Notes: Paired t-test for 12 pairs of responses out of a possible 29
* signficant ($p<0.05$), ** highly significant ($p<0.01$)

TABLE II
INDEPENDENT CHANGE IN CONFIDENCE (1-5) FOR LEARNING OUTCOMES

Learning Outcomes		Change in Confidence	Standard Deviation	Sig. *p* * ($p<0.05$)
1	The criteria for application of a robot to a specific task	0.58	0.77	* 0.023
2	How robots are interfaced	0.02	0.92	0.938
3	The limitations of a robot work envelope	0.72	0.92	* 0.018
4	The significance of cycle time	0.55	1.01	0.096
Average for all Learning Outcomes		0.47	0.94	0.064

Notes: Independent t-test for 19 pre & 21 post responses out of a possible 29

These results suggest that students' confidence has increased for the learning outcomes. However, the increase in confidence is not as great for the interfacing robots. The 2006-07 students were not given this confidence log; however, they were shown it during the focus groups and seemed generally confident about learning outcomes 1, 3 and 4, but less confident about robot interfacing. Some remembered interface buses being discussed in the meetings but were not certain what they were and identified this as a gap in their knowledge.

The Learning Resource Questionnaire [10] measures the frequency of use and the usefulness of the resources used by the students. The results are summarised in Table III. In general students seemed to use regularly: their own notes; the Internet; and discussions with students, used occasional: discussions with the tutor and textbooks, and used infrequently borrowed notes. They seemed to value all the resources mentioned, with the exception of textbooks and borrowed notes. This is not a subject covered well in textbooks so this result is expected. Similarly borrowed notes are not expected to be useful in this context. The use of their own notes is perhaps surprising, but may suggest that some of the anticipated integration of other aspects of the course into this activity. The high level of usefulness of the lectures may be a reference to industrial lectures in particular. It is perhaps surprising also that the Internet does not have higher reported usage and usefulness than it does. It is, however, reassuring that discussion with students is both regular and useful, suggesting functioning team meetings. The result that discussion with tutors was occasional but useful may be reflecting the contact time of half-an-hour per week. It is perhaps reassuring that the students are using and valuing a range of resources.

TABLE III
LEARNING RESOURCE QUESTIONNAIRE

Resources	Frequency of Use 1 – Did not use *to* 4 – Used Regularly	Usefulness 1 – Useless *to* 4 – Vital
Lectures	N/A	3.5
Textbooks	2.6	2.7
Own notes from lectures or labs	3.7	3.4
Borrowed notes	2.0	2.6
Discussion with tutors	2.9	3.4
Discussion with students	3.4	3.3
Internet	3.6	3.2
Other	2.8	2.6

Note: 21 responses out of a possible 29

The Perceptions to PBL questionnaire is a bespoke questionnaire generated for the IET PBL initiative, its results are summarised in Table IV.

TABLE IV
PERCEPTIONS OF PBL QUESTIONNAIRE

Statement (slightly abbreviated here)	Agreement 1 – Disagree Strongly 5 – Agree Strongly
I like PBL	3.3
I learn more from PBL than lecture based courses	3.1
PBL takes more time than lecture based courses	3.3
I have to take more responsibility for my learning in PBL	3.5
I enjoy working in a group	4.1
I clearly understood the problem given to me	3.7
I easily understood what was required of me in answering the problem	3.6
I was happy with the level of support provided by staff during the PBL	3.8
I prefer to learn through conventional lectures	3.0
I would like to learn in this way again	3.6
PBL has made me better at knowing how to find and use information	3.5

Note: 21 responses out of a possible 29

There is a generally positive reaction to the PBL exercise, with the students: particularly enjoying the group work aspect of the course, they were also happy with the level of support provided. They also understood the problem and what was required from them and would like to learn this way again. They were more neutral about preferring to learn through lectures or whether they learnt more through the PBL activity.

Assessment

All the posters were of a very high standard and covered the majority of the points that they were expected to cover. The groups showed a creativity and divergence in their solutions. Accordingly, the marks (summarised in Table V) for this aspect of the course were high; all posters received a first-class grade. The marks are consistent across both years of the course (independent *t*-test, *p*=0.61).

TABLE V
COMPARISON OF COURSEWORK AND EXAMINATION MARKS FOR 2005-06

Year	Mean	Standard Deviation	Number
2005-06	8.00	0.63	6
2006-07	8.25	0.87	4
Across Years	8.10	0.70	10

To give an impression of the variety of solutions thumbnail descriptions are provided below.

In 2005-07, Wigan Weight Watchers received a variety of proposals for their watercress soup plant: most involved medium-sized, six-axis robots. However, one involved a larger gantry robot, with the cans arranged for palletisation by a bespoke staking system prior to being moved into the boxes *en-masse* by the robot with 12 magnetic grippers. Another proposal used smaller, ceiling-mounted SCARA robot, mounted on a Gantry robot to reach between the conveyer-belts, again the 12 cans are arranged in the magnetic gripper in the palletised formation before being carried to the boxes. Magnetic grippers were a common solution, though one group selected a vacuum gripper. A number of the groups block moved a number of cans. These groups also used methods of rotating the can on the conveyer-belt past the bar-code reader. Some groups included 'wrong can scenarios' to reject cans with the wrong bar-code.

In 2006-07, Wigan Waggon Works Wheel Warehouse received a variety of proposals for their painting process. Many groups used heaters and ovens to shorten the drying time and hence the number of wheels circulating the painting shed waiting for re-coating. One group used palettes with radio-frequency tags to track the stage of completion of the wheels and a large drying hanger as a storage buffer. A variety of grippers were suggested, including one bespoke gripper designed to grip the internal diameter of the rim through 6 extending fingers. One group used two spraying robots to paint the fronts and backs of the wheels at once, another opted to dip the wheels for the rust-proof paint instead.

Focus Groups and Observations

The results of a number of focus groups, interviews and observations will be drawn together into a number of common themes reflecting the experiences of the two years of students.

Generally, the students enjoyed the exercise, particularly the opportunity to work together, collaboratively in a group. They felt that you found out more information through doing individual research and that that information 'sticks in your head more'.

Interestingly, many students immediately related this activity to previous project work that they had done, rather than considering it as a 'new' type of activity. The difference in scale of the activity was however noted 'this is the shortest project I have ever done'.

One criticism sometimes made of PBL is that it takes up more time. All the students felt that the time that they spent on the task was just right for the level of credit associated, and that the time frame it was extended over appropriate as well. They recognised that by working as a team they could work very efficiently on the activity.

There were however differences in the delivery of the activity between the years that had an impact on the experiences of the students.

In 2005-06, the exercise was held after the Easter vacation. These groups found this problematic, feeling pressure from finishing their final year projects. This is an example of how a module does not run in isolation, but is affected by the other modules running around it. In 2006-07, the exercise was moved to before Easter. This seems to have been an effective change, since all but one students asked thought that the timing of the activity was good. The one exception had a number of laboratories and laboratory reports about the same time as the PBL activity. This occurrence is difficult to allow for, since the scheduling of third-year laboratories means different laboratory groups have different laboratory timetables.

Another difference between the years was the scenario. Students from 2005-06, generally thought that the scenario was not challenging enough. They felt that by going through the process, they could generate an adequate solution without much difficulty. This view was shared by a group, who for a variety of circumstances, consisted of 2 instead of 5 students. The scenario 2006-07 was more complicated, involving two processes, material handling and painting, with the added complication of multiple coats of paint and an hour drying time per coat. This new scenario did not receive the same criticism. Most students found that it was difficult enough to interesting and engaging, but not so difficult that they felt stressed or stuck.

Associated with the difficulty of the scenario are the constraints associated. Generally, it was felt that the scenarios could be improved by introducing more constraints. Students from both years commented on the fact that cost not being an issue meant that very expensive solutions could be chosen without consequence. Some suggested introducing artificial prices to provide a constraint without the burden of sourcing real costs. The groups were encouraged to make assumptions about the scenario. Some suggested that this meant that some of the potential difficulties of the scenario could be circumvented by simply making the appropriate assumption. It was also observed that since the groups essentially made different assumptions about the scenario, they had all solved slightly different problems. Clearly, getting the balance between the constraints in the scenario and providing an open enough scenario to allow students to express their creativity is a fine one. It is gratifying that students wish to be challenged more. Despite these comments, they all spoke enthusiastically about the scenario and were very interested in the approaches that the other groups took in addressing it.

All the students spoke very highly of the industrial lectures, finding them motivating and informative. One student even described that from having no interest, he is now considering a career in robotics.

The other resource associated with the PBL activity was the *Workspace* program. Some students used this program to produce a three-dimensional CAD drawing of their robotic system. Some students were very excited about this program and would have liked to learn more about it, envisioning doing a simulation project with it. Having done the *Workspace* laboratory and the systems integration activity, they could clearly see how the two activities linked together and the next stage in the systems integration would be to simulate a robotic cell in *Workspace*.

As well as looking at company websites, some groups described contacting companies directly and receiving additional information about their products. They recommended future groups try this.

Teamwork came up a lot in students' discussions, many talked about enjoying the opportunity to work in teams. Others thought that it was a good preparation for industry and thought that the practice of working in pre-selected instead of self-selected teams was important. Some students described the importance of getting to know the strengths and weakness of their team mates and even spending time at the beginning to get to know them on a social level. It has to be said that both years seemed well disposed to teamwork. This may be the nature students that select Mechatronics or may be that being on a relatively small programme, sharing a number of core modules a sense of familiarity and cohesiveness has already been developed.

CONCLUSIONS

This paper describes the implementation of PBL, a form of EBL, into a third-year, Robotics module in the form of a systems integration exercise.

The results from the evaluation questionnaires suggest that the students learnt from the process, engaged in and valued group discussions and research on the Internet, valued the supporting lectures and were generally well disposed to the process. There was concern from the students that they had not really understood the issue of interfacing with robots.

The posters that they produced from the process were of a high quality, demonstrating the required learning as well as flexibility and creativity in their approaches.

The experiences and reactions of the groups involved, captured through participant observation and focus groups, were presented, showing that this activity was well received, but its timing in the term and the challenge of the problem were important to the students' experience.

We would like to conclude that introducing EBL into this module was a very worthwhile and successful activity. There is a very good match between the practical, process-based skill of systems integration and the process-led learning that characterises PBL. Students also felt a strong relationship between this more practical PBL activity and the project work they had engaged with at other times in the course. Consequently, they did not perceive it as a radically different form of learning.

ACKNOWLEDGEMENT

The authors would like to acknowledge the expertise and support from colleagues in the HEFCE/IET PBL in Electrical Engineering Project and the Centre for Excellence in Enquiry-Based Learning (CEEBL). The authors would also like to thank the students who participated in the EBL exercise and its evaluation. The authors are very grateful to David Hopper, Technical Director of RTS Flexible and Ian Coupland from ABB Robots, for their advice on the systems integration scenarios and their stimulating industrial lectures.

REFERENCES

[1] The Institution of Engineering and Technology (2007), *Problem Based Learning Initiative*, 2007. [Online]. Available: http://www.iee.org/professionalregistration/accreditation/pbl.cfm

[2] Mills, J. E. and Treagust, D. F. "Engineering Education – Is Problem-Based or Project-Based Learning the Answer?", Australian Journal of Engineering Education, 2003. [Online]. Available: http://www.aaee.com.au/journal/2003/mills_treagust03.pdf

[3] Kahn, P. and O'Rourke, K. *Guide to Curriculum Design: Enquiry-Based Learning*, Higher Education Academy, York, 2004. [Online]. Available: http://www.heacademy.ac.uk/resources.asp?id=359&process=full_record&section=generic

[4] Perrenet, J. C., Bouhuijs, P. A. J. and Smits, J. G. M. M., "The Suitability of Problem-based Learning for Engineering Education: theory and practice." Teaching in Higher Education 5(3), 2000, pp. 345-358.

[5] Powell, N. J., Hicks, P. J., Truscott, W. S. and Canavan, B., "Problems in the Semiconductor Industry: Teaching Design and Implementation of VLSI Systems using Problem-Based Learning", *6th European Workshop on Microelectronics Education*, Stockholm, Sweden, June 2006, pp. 1-4.

[6] Powell, N.J., Hicks, P. J., Green, P. R., Truscott, W. S. and Canavan, B., "Preparation for Group Project Work – A Structured Approach", *International Conference on Innovation, Good Practice and Research in Engineering Education*, Liverpool, July 2006, pp. 334-340.

[7] Brown, I., (1999). *Workspace 5.04: User Manual*, Flow Software Technologies.

[8] Draper, S. W., Brown, M. I., Henderson, F. P. and McAteer, E., "Integrative Evaluation: An Emerging Role for Classroom Studies of CAL", *Computers in Education*, 26(1-3), 1996, pp. 17-32.

[9] Biggs, J., Kember, D. and Leung, D. Y. P., "The revised two-factor Study Process Questionnaire: R-SPQ-2F", *British Journal of Educational Psychology* 71, 2001, pp. 133-149.

[10] Brown, M. I., Doughty, S. W., Draper, S. W., Henderson, F. P. and McAteer, E., "Measuring Learning Resource Use", *Computers in Education*, 27(2), 1996, pp. 103-113.