1. Project Title

Working with Industry to Create Collaborative Research Opportunities

2. Keywords

Problem-based learning, research, industry, partnership, construction project management.

3. Summary

This document reports on the activities that were part of my Reinvention Centre Fellowship project and their influence on the students' learning. My fellowship was based on a simple idea where a group of students supervised by an academic worked closely with project sponsors in host companies. The aim was to help companies:

- Solve pertinent business problems;
- Conduct (market) analysis/research to back up proposals;
- Interpret emerging legislation, e.g. recent changes to Part L of Building Regulations, for host companies. What does it mean for them?

by facilitating the interaction that is illustrated in Figure 1.

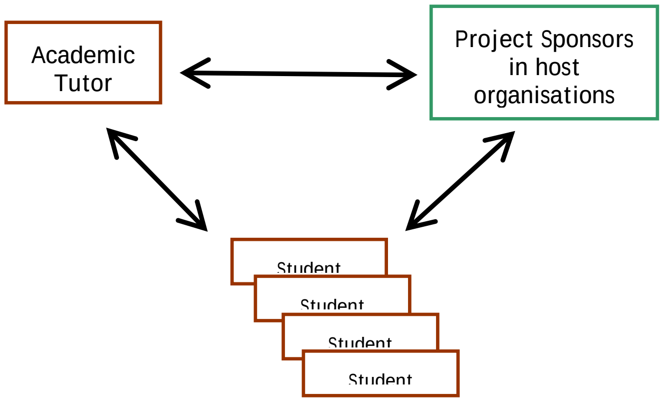

Figure 1. Relationships Diagram

In 2007-08, I ran a research-centred pilot scheme in a second year UG module, namely U33529. A group of six students volunteered to take part. The pilot scheme was a research project that aimed to determine whether refurbishment was more 'environmentally friendly' than new build. Our interim project report summarised the pilot scheme and the lessons learnt as a result. The main outcome of the pilot scheme was that the students found it very beneficial. They suggested that it should be offered every year and more companies should be involved.

On the strength of this outcome, I rolled out the scheme to the whole class in 2008-09. During the first semester, the economy had started to show signs of strain that resulted in an unprecedented downturn in property development activities on which this module heavily relies. Hence, it became almost impossible to find companies who would be willing to play a central role in this scheme. The only viable solution was to accept that there would only be one host company and that this company would play a peripheral role in this scheme. After much searching, New Swindon Company (NSC), which coordinates the regeneration of Swindon, accepted that one of their projects could be used to provide context for the students' research. It was made clear from the outset NSC could only facilitate a visit to the site and provide some information to the students.

4. Activities

Interim report includes a detailed account of work-packages 1-4. Hence, only work-packages 5-7 and associated activities are discussed in this final report. These work-packages were completed between October'08 and end of August'09.

4.1 Work-package 5 (WP5): Roll-out the main scheme in 2008-09

A literature review conducted in October'08 revealed a wide-range of methods approaches to engage undergraduate students in research. They included: problem-based learning (PBL)(Simm, 2005; Jenkins, 2006; Allen, et al 2003; Lee, 2001 , student volunteering programs(Edwards et al, 2007a) and research projects(Healey, 2005; Bolander, 2000). A review of the different approaches identified PBL as potentially the most appropriate one for engaging the U33529 students in research, mainly as a result of its merits of delivering/enhancing non-technical skills into students, e.g. communication, presentation, team working, report writing, data analysis. The module design was slightly altered so that it could be delivered using PBL.

Other changes included giving the student groups an opportunity to choose the topic that they were most interested and thus increase their motivation. Hence, three research themes were identified for the students to choose from during the first session of the module. Another important change was the assessment criteria to make sure that an accurate assessment of the students' knowledge and research skills development could be made.

4.2 WP6: Evaluate the main scheme & develop strategies for its sustainability

The pilot study was evaluated in June 2008 by using a questionnaire which included open and closed questions. The response rate for this survey was 83.33%. One major outcome of the survey was that all the respondents agreed that the pilot scheme was beneficial, with 20% "strongly agreeing". Furthermore, they all agreed that the scheme should be run every year with 40% strongly agreeing. It was against this background that the scheme was rolled out to the whole cohort in 2008-09. At the end of the module, an *electronic survey* on Brookes Virtual was used to collate feedback from the students on the scheme. The response rate to this second survey was 62%.

4.2.1 Comparison of pilot study survey with the main scheme survey

In any newly-introduced module it is imperative to know the main benefits of the course, the skills acquired from the course, the students' perception of the learning resources and possible suggestions for future improvement. Both surveys were conducted with these requirements in mind.

Considering that the pilot study sampled only six students, it was necessary to invoke the sample error into the calculations before comparing with the whole sample. This was important if any meaningful conclusions were to be drawn. Hence a sample error of 37% was used. This is a reasonable percentage given that for a sample size of 100 interviewees, the sample error is around 10% (UC 2009). For clarity, the following abbreviations and tables have been used.

NR1: Number of respondents in the pilot study

NR2: Number of respondents in the roll-out study

%A1: Response rate in the pilot study

%A1(37%SE): Corrected response rate in the pilot study with 37% sampling error

%A2: Number of respondents in the roll-out study

PR: Progress from pilot to roll-out study

NR2/NR1: Ratio of respondents in the roll-out study to pilot study

APR: Absolute progress taking into consideration the sampling error

The survey questions are analysed in tables below.

Table 1: Main benefits

What were the main benefits that you gained from the emphasis on research?								
	NR1	**%A1**	**%A1(37%SE)**	**NR2**	**%A2**	**PR**	**NR2/NR1**	**APR**
Improved research skills	5	80	50.4	22	71	-9	4.4	20.6
Gained new knowledge	6	100	63	21	68	-32	3.5	5

From the above table, it is evident that the students in both the pilot and roll-out study improved their skills as well as gained new knowledge. The last column in the Table 1 shows that about 20% progress has been made in terms of the percentage of students who think they have improved their research skills through this scheme, while only 5% progress has been made in terms of their perception of gaining new knowledge. This is an interesting and potentially important finding which may relate to students' perceptions of the role research activities play in gaining new knowledge.

Table 2: Skills acquired

If you feel you have developed/enhanced research skills, which skills do you think you developed/enhanced?								
	NR1	**%A1**	**%A1(37%SE)**	**NR2**	**%A2**	**PR**	**NR2/NR1**	**APR**
Data collection	5	80	50.4	17	53	-27	3.4	2.6
Data analysis	2	40	25.2	11	34	-6	5.5	8.8
Critical analysis of facts	5	80	50.4	13	41	-39	2.6	-9.4
Arriving at conclusions based on evidence	3	60	37.8	12	38	-22	4.0	0.2
Writing reports	1	20	12.6	15	47	27	15.0	34.4
Team-working skills	3	60	37.8	19	59	-1	6.3	21.2
Skills in networking	1	20	12.6	10	31	11	10.0	18.4
Self reliance in decision making	3	60	37.8	12	38	-22	4.0	0.2

Communication skills (writing, dissemination and presentation)	5	80	50.4	18	56	-24	3.6	5.6
Bibliographic skills	1	20	12.6	9	28	8	9.0	15.4
Computer skills	1	20	12.6	4	13	-7	4.0	0.4
Information search and retrieval skills	5	80	50.4	9	28	-52	1.8	-22.4
All of the above				2	6	6		6
None of the above				2	6	6		6

Generally Table 2 reveals a significant gain in skills except in *critical analysis of facts* and *information search and retrieval skills*. Given that *analysis* and *information search and retrieval* skills are related to learning resources and research materials, these results appear to be a surprise in the sense that they are not backed by those of Tables 4 and 5. Since *analysis* and *information search and retrieval skills* are directly related to learning resources and research materials, we should have expected a high demand of this resources and research materials in the roll-out than in the pilot study. On the contrary the demand dropped with differences of -19.05% and -6.8%.

Table 3: Emphasis on research skills

To what extent do you think the emphasis on research helped you develop and/or enhance your research skills?								
	NR1	**%A1**	**%A1(37%SE)**	**NR2**	**%A2**	**PR**	**NR2/NR1**	**APR**
To a large extent	3	60	37.8	5	16	-44	1.7	-21.8
To somewhat large extent	1	20	12.6	15	47	27	15.0	34.4
Neutral	1	20	12.6	5	16	-4	5.0	3.4
To a limited extent		0	0	4	13	13		13
Not at all				3	9			
Not sure				0	0			

From the above table it can be inferred that the module enhanced the students' research skills with 47% agreeing to have gained research skills. Compared to the pilot study, this is a great improvement of around 34.4%.

Table 4: Perception about learning resources

How did you find the learning resources (tutor support, lectures, tutorials, handouts, web and physical references, responses to questions) for this module?								
	NR1	**%A1**	**%A1(37%SE)**	**NR2**	**%A2**	**PR**	**NR2/NR1**	**APR**
Poor			Not examined	2	6	6		6
Below average	3	35	22.05	1	3	-32	0.3	-19.05
About average	1	20	12.6	11	34	14	11.0	21.4
Good	4	45	28.35	14	43	-2		14.65
Very good			Not	4	13			13

			examined					

Examining the above table a significant number of respondents confirmed the resources to be acceptable with 34% and 43% stating them to be average and good respectively. Furthermore there was a significant drop of about 19.05% of resources deemed below average. This is consistent with the improvement made based on the views of respondents in the pilot study.

Table 5: Suggestion for improvement

What improvements to this module would you suggest?								
	NR1	**%A1**	**%A1(37%SE)**	**NR2**	**%A2**	**PR**	**NR2/NR1**	**APR**
Enrich the course content	1	20	12.6	12	41	21	12.0	28.4
Increase the duration of lecture hours	6	100	63	2	7	-93	0.3	-56
Increase the frequency of meeting with lecturers	1	20	12.6	10	36	16	10.0	23.4
More learning material on research should be provided	3	60	37.8	9	31	-29	3.0	-6.8
Other	2	40	25.2	8	28	-12	4.0	2.8

From Table 5, fewer students in roll-out module have requested learning materials than in the pilot study. However, the percentage of respondents requesting for more learning materials is 31% which is quite high.

5. Outcomes

One of the main outcomes of this fellowship project is that PBL provides an opportunity to develop research skills of students studying for a Construction Project Management degree. Table 2 lists the wide range of skills that the students think they have developed.

This very encouraging finding is against a background where some findings of the survey and informal discussions with the students during module delivery pointed to a gap between the students' perception of the role research can play in their learning. Table 5 shows that nearly 40% of the students that took part in the pilot study and 31% of those who studied the module in 2008-09 require more learning material on research. This requirement from students suggests that their approach to research-based learning is similar to traditional forms of learning. This poses an important challenge to anyone who wishes to use research as a means to facilitate learning as this form of learning requires an attitude change on behalf of the students which can only be developed over a long period of time.

6. Implications

There are three main implications of this project.

Firstly, the students need to be prepared for a different teaching approach. Integration of research into teaching is best considered at programme level and students' preparation starts at the beginning of their programmes.

Secondly, finding companies who would be interested in the scheme and sustaining their interest are the main challenges to any module leader who would like to implement a similar scheme. This problem is exacerbated at economically challenging times such as this one.

Thirdly, our analysis of the assessment of learning in a group setting and learning individually, which is presented in the attached manuscript, shows that an approach that would enable the lecturers to assess the students' performance in individual and group settings is required to ensure that all students achieved the learning outcomes of a module. Such an approach also helps to reduce the inconsistencies that are inherent in assessing group-work.

7. Resources

The financial resources that were provided from the Reinvention Centre were instrumental in conducting this research project. All budget items that were identified as part of the application have been retained and monies allocated to these items have been used.

8. References

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10. Supplementary information

A manuscript detailing the assessment of students' research skills and their longitudinal development is attached. We aim to submit this paper for review to Assessment and Evaluation in Higher Education.

A mathematical model for assessing and evaluating students

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Abstract
The skills acquired during university and college education play a crucial role in determining the nature of employment a graduate would secure at the beginning of his/her professional life. Given that both academia and industry are now shifting emphasis from the development of only technical skills to developing both technical and non-technical skills of graduates, one of the major challenges facing higher education institutions (HEIs) is how to ensure that this aspiration is achieved in order to enhance the employability of their graduates. The development of non-technical skills requires a different teaching and learning approach from the conventional topic-by-topic learning methods, which have a notable longstanding success especially in delivering technical skills. Consequently, many higher institutions of learning are now adopting different approaches to deliver non-technical skills, e.g. communication, presentation, team working, report writing, and data analysis. One such approach is the Problem-Based Learning (PBL). While PBL has a number of advantages, placing students in both the conventional classroom and the non-conventional out-door environments makes assessment and evaluation of the students' skills a very complex task. Consequently, a cocktail of methods are being used to assess and evaluate the students. However, none of these can be said to accurately measure most of the non-technical skills. This paper attempts to fill this gap by developing a holistic mathematical model of assessing and evaluating these skills more efficiently and accurately. To put the model into context, two methods of assessment and evaluation are proposed. The proposed model and methods are designed on the basis of a rigorous review of literature on current assessment and evaluation techniques used in different HEIs. A second year course in the Department of Real Estate and Construction at Oxford Brookes University, which has recently adopted a PBL approach, is used as a case study to validate the model.

***Key words**: PBL, assessment, evaluation, mathematical model.*

Introduction

PBL has gained prominence in most HEIs (Hmelo-Silver *et al*., 2007; Rhem, 1998; Sejers *et al*., 2001). While it is acknowledged that the conventional topic-based methods of learning have proven successful in assessing and evaluating students for many decades (Feng Yin, 2006), such methods have been biased towards technical skills (Clarke, 2005; McGuinness & Bennett, 2006; Kolmos, 2006). A state-of-the-art review of the different assessment and evaluation techniques being currently undertaken in HEIs reveals a number of key issues. First, there is not a single perfect method for assessing and evaluating students. Assessors use a single

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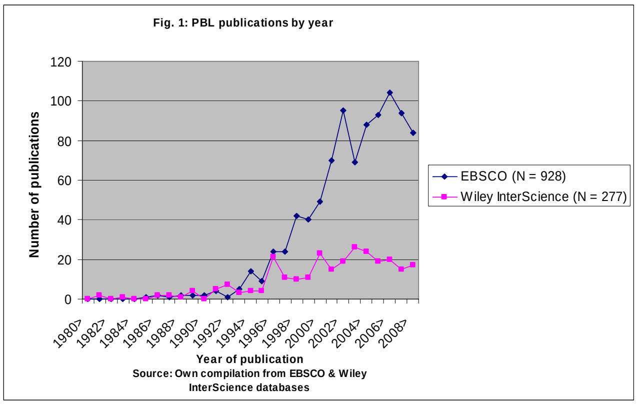
or a combination of methods, depending on a number of factors, including budget constraints, class size, assessor's preference, etc. Secondly, there is overwhelming evidence suggesting that most assessors neglect the student characteristics in establishing the suitability of the assessment methods (Stewart, 2006; Darby, 2007; Knox, 2002). Oral examination, for example, may be limited in measuring the presentation skills of an international student whose first language is not that of the host institution. These students would require different methods which can only be designed after conducting needs assessment. But with an increasing number of students with ever decreasing resources, needs assessment is often not undertaken. Related to needs assessment is the issue of taking stock of students' abilities at the time they are commencing their course. It is important to know the abilities of the students at entry point so that it will be easier to determine their achievements at exit point. Also stock-taking at the commencement of the course creates a benchmark against which to assess the skills the student may have gained. These complexities of assessment and evaluation approaches dictated by so many constraints, higher expectation of students output, and the exigencies of the employment market are challenging and place assessors in a choice dilemma.

In order to address the above challenges, this paper proposes a holistic, multi-variable mathematical model for assessing and evaluating students' coursework. The model facilitates understanding of various assessment variables. It also incorporates factors such as previous skills possessed by students and the needs of individual students which are currently often overlooked by most assessors. The strength of the model lies in its simple, unique ability to adjust the overall mark by the introduction of coefficients. The model can be used to determine a student's mark with high degree of certitude, as well as his/her level of participation in class. It contains a constant that reflects the different factors that can affect student participation in group and individual work (e.g. differences in cultural background, language limitations, etc). Such factors may influence the performance of students differently and as such need to be taken into consideration when assessing and evaluating students.

This paper was motivated by the recent changes to a PBL-based module in the Department of Real Estate & Construction, Oxford Brookes University. The module is compulsory for second year students studying BSc (Hons) Construction Management. In order to meet the requirements of the module, it was felt important to develop a simple and easy-to-use assessment and evaluation technique. The module is used as a case study in this paper to test and validate the model.

The Emergence of Problem-Based Learning

Although its intellectual history is far older, the history of modern PBL dates back to the 1970s when it was conceived at the medical school at McMaster University, Canada (Rhem, 1998). This perhaps explains why until recently the uptake of PBL has been more in medical schools (*ibid*). As a subject for academic enquiry, however, it was not until the early 1980s that interest in PBL started to gain widespread currency across the globe and other subjects. This can be evidenced by the rapid growth in the number of publications on the subject, particularly in the 1990s (Fig. 1).



The figure shows the number of publications with titles containing "problem-based learning". These were obtained by executing a search (ordered by publication date) from two of the world's leading scientific publication databases, EBSCO and Wiley InterScience. It is evident from the graph that despite the decline in publications in some years, the general trend is that there has been an increase in the number of publications, particularly from the 1990s.

Since the 1990s, PBL has become a contested concept, spreading across other domains including social sciences and humanities, with each struggling to understand it.

Although there are many definitions of PBL (e.g. Rhem, 1998; Finkel and Torp, 1995) the common characteristic among the definitions is that the concept seeks to encourage students to learn content, strategies and self-directed skills through collaborative solving of contextualised, ill-structured problems while reflecting on their experiences and engaging in self-directed enquiry (Hmelo-Silver *et al*, 2007). Hmelo-Silver *et al* (2007) further point out that one of the key salutary effects of PBL is 'scaffolding"- a process where students learn through guidance from mentors in the form of coaching, task structuring and giving them hints on tasks but without explicitly giving the students final answers. The importance of this feature is its ability to support students' learning in terms of how to do the task, as well as understanding why the task should be done in that particular way.

The key characteristic of PBL is its emphasis on *collaboratively engaging learners in finding solutions to real world complex problems by sharing information and exploring alternatives*. It orients learners towards meaning-making over fact-collection. This unparalleled ability of PBL can perhaps be better summarised by one famous Chinese proverb (Hmelo-Silver *et al*, 2007: 105):

> "Tell me and I will forget; show me and I may remember; involve me and I will understand"[1]

By involving the learners as the above quote suggests, PBL stimulates learning experiences which yield knowledge that the learners would retain and apply to real life professional settings. This, however, poses additional challenges to the lecturers in terms of which assessment and evaluation technique to use.

Current assessment and evaluation techniques

Assessment can be defined as the gathering of feedback on the learning process, understanding the meaning of this feedback, and using the feedback to improve

[1] After the Chinese social philosopher Confucius (551 – 479BC)

teaching-learning process (Huba and Freed, 2000). It is the process of documenting, in measurable terms, knowledge and skills gained by students. On the other hand, evaluation is generally a systemic determination of merit, worth and significance of something using methods against a set of standards. Educational evaluation, which is our interest in this paper, is thus a systematic way of determining whether or not a student has actually mastered a concept (*ibid*).

There are generally two types of assessment: summative and formative (Rhem, 1998; Boston, 2002). The former is a process whereby students are assessed at the end of an activity or timeframe (e.g. module, semester, etc.) while the latter entails assessing the students throughout the learning process (*ibid*). Summative and formative assessments are synonymous with what Earl (2003) has called 'assessment *of* learning', and 'assessment *for* learning', respectively. The two forms of assessment can best be distinguished by Robert Stake's (cited in Earl, 2003) analogy of tasting soup – *when the cook tastes soup, that is assessment for learning; when the guests taste soup, that is assessment of learning*. The purpose of summative assessment, writes Earl, is to certify learning by allocating marks thereby ranking the student in relation to other students. This type of assessment has dominated the education assessment system for many years. The assessors are usually in firm control of creation and marking of examinations. The students have no influence on the process. Also, the fact that learners are compared through allocation of marks means that there will be little room, if any, for students' improvement. Furthermore, the allocation of marks is problematic in that it is subjective and as such it is potentially susceptible to bias. Besides, it is difficult to assess a student within a short period of time over so many skills acquired during the normal teaching period. Also, the student will not be able to tell in which area his/her strengths are if awarded a single mark at the end of the semester.

Formative assessment was conceived to address the flaws inherent in summative assessment. The process entails teachers collecting data about their students so that they modify tasks as need arises during the learning process. The teacher-student interactions and feedback are conducted more than once during the learning process so that teachers can identify areas that need improving. The purpose of these middle-of-learning 'checks and balances' is for the teaching staff to better the next strategies. Formative assessment will thus benefit students in that they tend to build on their strengths and improve upon their weaknesses over time based on feedback from teachers, lecturers, peers or self-discovery. However, because the method relies heavily on teachers, its success will depend on the skills of the teacher (Earl, 2003).

In addition to summative and formative assessments, Earl (2003) has proposed a more interactive method which she has called assessment *as* learning. Unlike the above two methods which regard the teacher as the master of knowledge, with students playing a peripheral role, assessment *as* learning acknowledges the potentially crucial role students can play in the learning process. The method engages students as active assessors who can monitor what they are learning. On the basis of this self assessment, students are able to make adjustments and adaptations.

Other than the above categories, some writers have grouped assessment into *group*, *peer* and *self assessment*. Yet others have broadly categorised them into *group* and *individual* assessment only. Rob East of the University of Glamorgan, UK, is one notable writer on these types of assessment. Contributing on the UK Centre for Legal Education (ukcle) website[2], East notes that the key advantage of group assessment is that it reduces the burden of marking from teaching staff. Furthermore, although group assessment is a very good vehicle for delivering communication, organisational, team and leadership skills, the inability to apportion the contribution of individual members of the group is its key limitation.

Peer assessment refers to assessment practices in which peers assess their fellow students. While the method has advantages over group assessment, the focus to assess the end product makes the method weak as it neglects the process that leads to that end product. Finally, self assessment refers to the process in which students assess their own skills (Topping, 2003). This reduces workload of staff, and the assessment itself is a valuable learning experience in that it promotes critical self reflection. However, self assessment poses a danger as students may tend to be too lenient on themselves.

Whether summative, formative, group, self or peer assessment, the success of these types of assessment will largely depend on the method of assessment used.

Methods of assessment

Various assessment methods have been used to measure students' performance (e.g. see Yin, 2006; Steward *et al.*, 2004; Thomé *et al.*, 2006; Keppell *et al.,* 2006; Chang and Tseng, 2008; Strauss and Alice, 2007). Essays, journals, examinations, reports and oral presentations are but some of the main assessment methods used by many HEIs. Table 1 shows these methods, their strengths and weaknesses.

Table 1: Common assessment methods

Method	Strengths	Weaknesses
Essays	Enhances communication, research, reading, self-management skills; Develop skills to search & select appropriate material	Too stipulative - teacher determines everything about the essay (topic, length, etc), thereby defying requirements for real-life documents like memos, etc; Too expert-oriented; Unlike real-life documents (e.g. journal articles), feedback is never part of final document
Journals	Allows students to modify article based on feedback; Real-life experience of writing articles; Enhances ability to take criticism & criticise.	Lengthy process; If group articles, always difficult to determine contribution of individual students
(Written) examinations	Inexpensive as many students are examined at once	Subject-specific; Difficult to assess non-technical skills
Report	Good at assessing time	As in essays above

[2] www.ukcle.ac.uk.

writing	management, task organisation, & writing/communication skills;	
Oral presentations	Enhancement of presentation/communication skills; Enables testing students' understanding of subject area	Time consuming for large classes; Bias/subjectivity in award of marks; In case of an appeal, evidence of details of the presentation unavailable

Choosing the most appropriate method

With so many methods at the disposal of assessors, the issue of which method or combination of methods to use can be challenging. The method(s) can be determined by, for example, the size of the class, the available resources, the type of skill to be assessed, and whether to assess individually or on group basis. Another determining factor is whether the skills to be assessed are general or core. The methods appropriate for core skills may not necessarily be appropriate for non-core skills (The Research Observatory, 2009). This deterministic approach to assessment can be costly, time consuming and inaccurate. The relevant question for us therefore is: can we have a method that can address these challenges?

It is on the basis of this challenging question that after a thorough review of other models (e.g. Raudenbush and Willms, 1995; Raudenbush, 2004; Braun, 2005; Dancer and Kamvounias, 2005; Hassanien, 2007; Tal, 2005; Elaine, 2003; Fellenz, 2006) the multi-variable assessment and evaluation mathematical model was developed. This was after realising that some of the models (for example Raudenbush and Willms, 1995; Raudenbush, 2004) are too complex to implement in practice while others cannot be applied in the case of this study because they are either too qualitative or descriptive to highlighting the key parameters (Hassanien, 2007; Tal, 2005; Elaine, 2003; Fellenz, 2006). Nonetheless, Dancer and Kamvounias' (2005) model was of relevance to this study because the model already contains some constants and variables that can be re-used in this study though a further generalised extension of the constants and variables was undertaken. Furthermore the form or dimension of the equation is ideal for the current study though a generalisation of the equation is required. Other than Dancer and Kamvounias' model, the application of mathematical models as tools of assessing and evaluating students is, at best, still work in progress. The following section begins by discussing Dancer and Kamvounias' model, outlining its strengths and weaknesses. The section then proceeds to present the proposed model.

Dancer and Kamvounias' model

The model was developed for the purpose of identifying criteria for assessing class participation using both the student and the tutor input in a large commercial law class. According to Dancer and Kamvounias, class participation mark can be represented by the model:

$$mark = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_3 C_3 + \beta_4 C_4 + \beta_5 C_5 + u_i$$

where C_1 = preparation, C_2 = contribution to discussion, C_3 = group skills, C_4 = communication skills, and C_5 = attendance, and u_i = the disturbance term. Although Dancer and Kamvounias do not define the β s, it can be construed that these represent coefficients that measure the contribution of the criteria to the students' final mark. One main achievement of the model is that it actually reveals how well a criterion could predict the class participation mark. However, in capturing group skills (C_3) and communication skills (C_4), the model creates an ambiguity in terms of what constitutes group skills and communication skills, given that communication skills are often considered as part of group skills (Rhem, 1998). Thus without a clear distinction, one may evaluate communication skills twice - as an independent variable C_4 and as a dependent variable in C_3. The Dancer and Kamvounias model also falls short when it comes to measuring students' progress, and absolute skills gained. These aspects are addressed in the proposed model.

The proposed model

In order to address the limitations of Dancer and Kamvounias' model above, the proposed model captures several variables of assessment in both individual and group work. This has two major advantages: first, it restricts reliance on one method of assessment at the expense of the others; second, it enables teachers to assess a wide range of skills. This is very crucial given that in life there exist two types of people - introverts and extraverts, with each of these types affecting students' performance differently on a particular skill. Furthermore, studies by Vandrick (2000) suggest that certain traits that may affect group participation are shyness, classroom dynamics (e.g. domineering students), culture (e.g. asking questions in some cultures can be seen as a sign of disrespect or challenge to a lecturer), gender, and language barriers. In order to capture these characteristics, we introduce in the proposed model the constants ${}_G\mu_0$ and ${}_I\mu_0$. ${}_G\mu_0$ captures the skills in a student that may be hindered as a result of the student participating in *group* work. For example, introverts may be affected from expressing themselves due to the presence of domineering students. ${}_I\mu_0$ captures skills in students, especially extroverts, that may be hindered by working alone. The constants ${}_G\mu_0$ and ${}_I\mu_0$ also assist in addressing the issue of variation in the needs of students. In order to capture the problem of resource constraints which is a common hindrance in assessing students, we have introduced weighting coefficients to the variables to be measured (α_i and β_j for moderating the marks of students assessed in group and individual work respectively). In a situation where the students cannot be assessed in a group, then the coefficients of the group variables are zero. If students can be assessed on group as well as on individual basis, then the coefficients of the variable is left to the assessor to fix depending on the circumstances. Another issue that we considered crucial in this model is the previous skills possessed by a student. This is taken care of by the introduction of a constant φ_0 which provides the baseline against which student's progress in a particular skill can be measured (Kyriakides, 2002; Darby, 2007).

The ensuing section presents the mathematical model described above. The assumption in this model is that the assessment using the group and individual methods is applicable to a single project or course module. For instance, in a given course module students may be split into groups and assigned to submit a journal paper (i.e. group assessment G; see Table 1 above) upon which they may be assessed on communication, presentation and subject understanding skills. Similarly students may be assigned to make individual oral presentations (i.e. individual assessment R; see Table 1) upon which they may be assessed on communication, presentation, subject understanding skills, management of audience, and critical thinking skills.

Let $\mathrm{G} = \{g_i : \ \forall i \in \aleph\}$ be the set of assessment variables using *group* assessment method where g_i are the assessment variables (e.g. communication (g_1), presentation (g_2) and subject understanding (g_3) skills), for all indices ($\forall i$) or positive integers denoting the variable belonging to $\aleph$, the set of natural numbers;

$\mathrm{I} = \{r_j : \forall j \in \aleph\}$ be the set of assessment variables using the *individual* assessment method where r_j are the assessment variables (e.g. communication (r_1), presentation (r_2), subject understanding (r_3) and IT (r_4) skills) for all indices or positive integers denoting the variable belonging to $\aleph$, the set of natural numbers. The sets G and I may not necessarily be identical though there may exist some elements common to both sets.

Suppose $M_{g_i} = \alpha_i a_i^{g_i}$ is the corresponding mark for the g-i[th] variable in the set G. Taking into consideration its weight with the parameter $\alpha_i \in [0, 1]$, then the total mark for n-variables taking into consideration constraints of assessment in group work is:

$${}_0M_G = \sum_1^n M_{g_i} = \sum_1^n \alpha_i a_i^{g_i} + {}_G\mu_0 \quad \forall i \in \aleph, \ \aleph \text{ is the set of natural numbers.}$$

Similarly we can define the total mark for the individual work as:

$${}_0M_I = \sum_1^m M_{r_j} = \sum_1^m \beta_j b_j^{r_j} + {}_I\mu_0 \quad \forall j \in \aleph, \ \aleph \text{ is the set of natural numbers.}$$

Given a_i and b_j are assessment marks in the group and individual work respectively, then the total assessment mark of a student $M_T = {}_0M_G + {}_0M_I$

In an ideal situation ${}_G\mu_0 \to 0$ and ${}_I\mu_0 \to 0$

Let's define $M_G(g_i) = \sum_1^n \alpha_i a_i^{g_i}$ and $M_I(r_j) = \sum_1^m \beta_j b_j^{r_j}$. Therefore, the combined assessment mark for both the group and individual work is

$$M_T = M_G(g_i) + M_I(r_j) = \sum_1^m \beta_j b_j^{r_j} + \sum_1^n \alpha_i a_i^{g_i} \qquad (1)$$

As earlier stated, students are often awarded marks for performing in a given skill. However, knowing the progress achieved by a student and the absolute skill gained (often called “value-added” skill (Kyriakides, 2002; Darby, 2007) is important in the learning process. We propose two methods of measuring students’ progress on a particular skill or group of skills. The progress made by a student will be defined as the skills acquired by the student during a course but measured at the end of the course. In practice, it is quite common to find that the progress of a student is attributed to the mark the student has earned in group work or individual work. But a student who inherits a group’s mark might not have contributed in the group work. Secondly, if we concentrate only on individual assessment, the group skills - an important component of PBL - will not be assessed. Thirdly we cannot immediately certify if the student actually deserved the marks without rigorous methods such as statistical analysis. Hence we present an approach that takes this into consideration. The ensuing sections present two approaches that further build on equation 1.

Method 1

Using (1) we define

$M_{Td} = M_{Gd}(g_i) + M_{Id}(r_j) = \sum_1^m \beta_j b_{jd}^{r_j} + \sum_1^n \alpha_i a_{id}^{g_i}$ where d denotes the 1st or 2nd time the assessment is undertaken, m and n denotes the number of assessment variables under consideration.

Firstly we assess the students on a number of variables by using

$$M_{T1} = M_{G1}(g_i) + M_{I1}(r_j) = \sum_1^m \beta_j b_{j1}^{r_j} + \sum_1^n \alpha_i a_{i1}^{g_i}$$

Secondly we swap the parameters g_i and r_j, i.e. assessing students on a variable through group work assignment in the first instance and then repeating the assessment on the same variables but now on individual basis. Thus,

$$M_{T2} = M_{G2}(r_j) + M_{I2}(g_i) = \sum_1^n \beta_j b_{j2}^{r_j} + \sum_1^m \alpha_i a_{i2}^{g_i}$$

In practical terms, we want to assess students on group work through the submission of a journal paper, for instance, based on some variables of assessment, g_i, and also on individual work through individual oral presentation on some variables of assessment r_j in the first instance (determines M_{T1}). In the second instance we want to assess students on group work through oral presentation by nominated group representatives using the variables r_j and also on individual work through the submission of individual journal papers on some variables of assessment g_i (determines M_{T2}).

Let’s define the deference between the two marks as ΔM

$$\Delta M = M_{T2} - M_{T1} = M_{G2}(r_j) + M_{I2}(g_i) - M_{G1}(g_i) + M_{I1}(r_j)$$

Since the goal here is to determine the progress made by a student in individual as well as group skills, similar parameters will be collected over individual and group terms as in (2). Thus,

$$\Delta M = (\sum_1^n \beta_j b_{j2}^{r_j} - \sum_1^m \beta_j b_{j1}^{r_j}) + (\sum_1^m \alpha_i a_{i2}{}^{g_i} - \sum_1^n \alpha_i a_{i1}{}^{g_i}) \quad (2)$$

From (2) the summation index does not really matter since each summation term is a real number hence we can set $\Delta I = \sum_1^n \beta_j b_{j2}^{r_j} - \sum_1^m \beta_j b_{j1}^{r_j}$ and $\Delta G = \sum_1^m \alpha_i a_{i2}{}^{g_i}$ - $\sum_1^n \alpha_i a_{i1}{}^{g_i}$

Hence, $\Delta M = \Delta I + \Delta G$

But $\Delta M = 0$ or $\Delta M \neq 0$

Model 1: ΔM =0

$\Delta M = 0 \Rightarrow \left|\frac{\Delta I}{\Delta G}\right| = 1$

In this case, it can be said that the student's group skills is the same as his individual skills and no much information can be deduced.

Model 2: $\Delta M \neq 0$

$\Delta M \neq 0 \Rightarrow \Delta I + \Delta G \neq 0 \Rightarrow \left|\frac{\Delta I}{\Delta G}\right| < 1$ or $\left|\frac{\Delta G}{\Delta I}\right| < 1$

If $\left|\frac{\Delta I}{\Delta G}\right|$<1, then it can be said that the student's individual skills are weaker than his/her group skills.

If $\left|\frac{\Delta G}{\Delta I}\right|$<1, the student's individual skills are stronger than his/her group skills. Furthermore there could be students with high individual skills but because of weak group members, their group mark is lowered. This requires further analysis using perhaps statistical techniques not considered in this paper.

Using model 1 and 2 we are able to certify that a student has acquired or not acquired any skills. The question is by how much? To answer this question we introduce in equation 1 a function φ_0, the initial skill level of the student before enrolling on a course. This function can be determined prior or after enrolling on a course using any appropriate knowledge acquisition method. Like G and I, φ_0 is defined as:

$\varphi_0 = \{q_s : \forall s \in \aleph\}$ be the set of assessment variables for skills of a candidate before enrolment on a PBL course and the total corresponding mark for φ_0, defined by M_{φ_0} is:

$M_{\varphi_0} = \sum_1^n \alpha_i q_i^{g_i} + \sum_1^m \beta_j q_j^{r_j}$ It is important to note that in a case where we are interested only in group skills, the coefficients β_j are set to zero $\forall j$ and vice versa. Hence to determine the real skill level of a student, equation 1 becomes

$$M_T(real) = M_G(g_i) + M_I(r_j) - M_{\varphi_0} \quad (3)$$

Taking into consideration individual or group components (3) becomes

$$M_T(real) = \sum_1^m \beta_j (b_j^{r_j} - q_j) + \sum_1^n \alpha_i (a_i^{g_i} - q_i) \qquad (4)$$

Method 2

One major disadvantage of the first method is that it is too expensive and time consuming, given that the assessor needs to repeat the assessment through swapping of the parameters. The second method considers that the evaluation process is undertaken once on variables that can be assessed and evaluated both in group and on individual basis. This means that the set G and I should be examined for those parameters that are common to both sets. Furthermore this method comes as a consequence or particular case of models 1 and 2. Models 1 and 2 indicate that the student's progress is measured as a ratio between the individual and group skills or vice-versa.

Let $z_i \in G \cap I,\ \forall i \in \aleph$ be the set of variables that can be assessed on both group and individual basis. We define the total marks for the common variables as $M_G^c(z_i)$, $M_I^c(z_j)$ for the group and individual work respectively.

$$M_{T1} = \sum_1^m \beta_j b_{j1}^{r_j} + \sum_1^n \alpha_i a_{i1}{}^{g_i}$$

$$M_G^c(z_i) = \sum_1^n \alpha_i a_i^{z_i},\ M_I^c(z_j) = \sum_1^n \beta_j b_j^{z_j}$$

$$M_{T1} = M_I^c(z_j) + M_G^c(z_i) = \sum_1^n \alpha_i a_i^{z_i} + \sum_1^n \beta_j b_j^{z_j} \qquad (5)$$

Similarly $M_{T1} \in N^+ \Rightarrow M_{T1}=0,\ M_{T1} \neq 0$

Model 3: $M_{T1}=0$

$$M_I^c(z_j) + M_G^c(z_i) = 0 \Rightarrow \left|\frac{M_I^c(z_j)}{M_G^c(z_i)}\right| = 1$$

Model 4: $M_{T1} \neq 0$

$$M_{T1} \neq 0 \Rightarrow \left|\frac{M_I^c(z_j)}{M_G^c(z_i)}\right| < 1 \text{ or } \left|\frac{M_I^c(z_j)}{M_G^c(z_i)}\right| > 1$$

Taking into consideration individual or group components (5) becomes

$$M_T(real) = \sum_1^n \beta_j (b_j^{z_j} - q_j) + \sum_1^n \alpha_i (a_i^{z_i} - q_i)$$

An Application of the model to the module "Integrative Building Project II"

Though we have presented the pros and cons of the two methods, we chose the second method for the implementation to our case study. This choice is based on the lower cost and time involved. The case study was designed to highlight the implementation of the components of the model hence depicting the similarities and dissimilarities. In order to facilitate understanding it is necessary to present a brief description of the module that has been introduced to enhance PBL skills in

Construction management students in the Department of Real Estate and Construction, Oxford Brookes University.

The case study model was designed in response to the criticisms in terms of the inadequacies of the current lecture-based teaching methods being used by many universities to deliver skills that employers are seeking in graduates (Clarke, 2005; McGuinness and Bennett, 2006; Kolmos, 2006). The module is also intended to enhance students' technical as well as non-technical skills. In order to achieve this, the formative assessment was implemented through group and individual work. In response to the demands of the industry (ibid) more emphasis was placed on developing group skills and as such the weighting coefficients for both group and individual work were chosen to be 40% and 60% respectively. The 40% accorded to group work is significantly higher than what is offered in practice as provided in the University regulations.. Taking into consideration the area of skills shortage identified in Clarke (2005), McGuinness and Bennett (2006) and Kolmos (2006) the following criteria were used in assessing students through group and individual basis: the *knowledge and understanding of subject*, the *use of literature and data sources*-, the *identification of principles and application*, the *quality of reasoning and analysis*; the *extent of analysis*; the *application to evaluation*; the *clarity and quality of presentation* and *referencing*. For simplicity reasons, these criteria will be denoted as g_1, g_2 g_3, g_4 g_5, g_6, g_7, g_8 (for group) and r_1, r_2, r_3, r_4 r_5 , r_6, r_7, r_8 (for individual) variables respectively. Furthermore Si (i: 1….48) represents the code for students that were examined in the module and the survey.

Table 2: Survey results of students

No	$M_I(z)$	$0.4*M_I(z)$	$M_G(z)$	$0.6*M_G(z)$	$0.4*M_I(z)/0.6*M_G(z)$	S	0.6*S	$0.4*M_I(z)/0.6*S$
S1	45	18	55	33	0.55	47	28.2	0.64
S2	45	18	65	39	0.46	55	33	0.55
S3	52	20.8	45	27	0.77	45	27	0.77
S4	45	18	65	39	0.46	40	24	0.75
S5	68	27.2	55	33	0.82	55	33	0.82
S6	42	16.8	51	30.6	0.55	41	24.6	0.68
S7	40	16	65	39	0.41	45	27	0.59
S8	66	26.4	55	33	0.80	57	34.2	0.77
S9	80	32	53	31.8	1.01	53	31.8	1.01
S10	44	17.6	65	39	0.45	55	33	0.53
S11	68	27.2	55	33	0.82	65	39	0.70
S12	56	22.4	65	39	0.57	45	27	0.83
S13	43	17.2	65	39	0.44	57	34.2	0.50
S14	55	22	55	33	0.67	55	33	0.67
S15	56	22.4	65	39	0.57	65	39	0.57
S16	30	12	65	39	0.31	55	33	0.36
S17	46	18.4	65	39	0.47	55	33	0.56
S18	54	21.6	55	33	0.65	45	27	0.80
S19	55	22	55	33	0.67	55	33	0.67
S20	58	23.2	45	27	0.86	40	24	0.97
S21	43	17.2	55	33	0.52	65	39	0.44
S22	80	32	51	30.6	1.05	47	28.2	1.13
S23	67	26.8	40	24	1.12	67	40.2	0.67
S24	54	21.6	65	39	0.55	65	39	0.55

S25	55	22	55	33	0.67	65	39	0.56
S26	50	20	65	39	0.51	35	21	0.95
S27	54	21.6	45	27	0.80	55	33	0.65
S28	54	21.6	55	33	0.65	52	31.2	0.69
S29	56	22.4	55	33	0.68	45	27	0.83
S30	55	22	55	33	0.67	60	36	0.61
S31	56	22.4	51	30.6	0.73	55	33	0.68
S32	65	26	51	30.6	0.85	55	33	0.79
S33	64	25.6	55	33	0.78	55	33	0.78
S34	57	22.8	45	27	0.84	55	33	0.69
S35	44	17.6	55	33	0.53	55	33	0.53
S36	46	18.4	51	30.6	0.60	55	33	0.56
S37	67	26.8	65	39	0.69	55	33	0.81
S38	68	27.2	65	39	0.70	50	30	0.91
S39	55	22	65	39	0.56	45	27	0.81
S40	45	18	55	33	0.55	55	33	0.55
S41	57	22.8	51	30.6	0.75	55	33	0.69
S42	57	22.8	55	33	0.69	55	33	0.69
S43	46	18.4	65	39	0.47	53	31.8	0.58
S44	41	16.4	55	33	0.50	50	30	0.55
S45	58	23.2	65	39	0.59	65	39	0.59
S46	53	21.2	55	33	0.64	41	24.6	0.86
S47	53	21.2	55	33	0.64	55	33	0.64
S48	46	18.4	65	39	0.47	58	34.8	0.53

In total 55 students enrolled for the module and were assessed. Out of the 55, only 48 had complete marks for both individual and group assessment and also participated in the survey. These 48 students are those that have been analysed and represented in Table 2.

The group was administered in two different stages: the interim presentation and final presentation representing 15% and 25% of marks respectively. This approach was adopted in order to provide a formative feedback for further development after the interim group presentation. The summation over g_i was made and represented as $M_G(z)$.

The individual assessment was through the submission of reports from a field trip to the Netherlands. In this trip the students were introduced to the Dutch development and planning practices. This resulted in an opportunity for students to develop an understanding of the Dutch approach to planning and development and observing a diverse range of large scale, complex projects. The students were provided with workbooks to keep record of their observations and for submission upon return. The summation over r_j was made and represented as $M_I(z)$. Upon calculation of all the $M_G(z)$ and $M_I(z)$ as in the models 3 and 4, their ratios were calculated taking into consideration their respective coefficients. The results reveal that about 94% of the students had stronger group skills than individual skills.

In order to validate the model the students were asked to submit a 1000-word reflective account clearly stating how the outcomes of the module were achieved. The marks for the reflective report are denoted S. The variable S was multiplied by 0.6, the coefficient of the group so that both can easily be compared. Taking the ratio of the individual to the reflective report marks, the outcome was similar to the ratio of the individual to the group marks. In fact the results stood at 96% confirming the validity of the results with a 2% difference. For the remaining 6% and 4% of the students with ratios of greater than one as per model 4, further statistical analysis needs to be undertaken.

Concluding remarks

With an increase in the demand for multi-skilled professionals in different sectors, the need for alternative methods, e.g. PBL, to produce such professionals will continue to grow. To maximise the potential benefits of PBL, appropriate assessment and evaluation techniques that will help establish whether the intended objectives of PBL have been achieved; the students' skills have been enhanced; and the skill level acquired by a student has been determined are necessary. This can be possible if there is a mechanism that can enhance the assessment tools in making decisions regarding which methods of assessments to use in a particular course, bearing in mind the possible implications. It is in light of this and other limitations that the holistic mathematical model was developed to facilitate the decision-making in assessing and evaluating students. The model can be implemented in any database management system which will only require the relevant cells to be populated with relevant assessment data.

The strength of the model lies in its ability to take into consideration all the relevant variables of assessment that are aimed at enhancing lifelong skills in students. It should be stated here that the model does not preclude the teachers' freedom to leave out some variables. It actually permits assessors to choose the variables that they would want to use depending on, for example, the available resources and appropriateness of the variables. Other than its ability to accommodate many variables at once, the strength of this model is also the fact that it does not dictate how the variables should be graded. This makes it very flexible for use by assessors using different grading scales. This notwithstanding, the effectiveness of the proposed model relies heavily on the accuracy of the uploaded assessment data (or variable scores/values). How to determine the authenticity of, and allocate values to the variables considered in the model still remain a challenge and a matter for further research. We have however used the standard mathematical methods such as summation, inequalities and ratios to execute and deduce important facts and confirmed the authenticity of the marks acquired by students through a simple survey method. The other limitation of the model lies in the difficulty associated with the determination of coefficients. This is the main limitation of method 2. Because of the swapping of parameters, the errors accrued as a result of the difficulties in determining the coefficients are absorbed. Furthermore, despite its strengths as explained in this paper, it should be stated here that the model is not in itself a panacea to the inherent problems in the current assessment methods. Like any other model, its success will largely depend on the willingness of the assessors to use it.

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