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A Vector Approach to the Assessment of Undergraduate Engineering Courses*

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In any undergraduate engineering programme there is a need to assess the balance and flavour of the various educational strands. In order for a quality assurance of these programmes to be met there is a need to evaluate the course load, academic content and the assessment marks of each course in the undergraduate programme. The existing ranges of QA methods for these programmes are focused on one or two of these issues and do not provide a comprehensive assessment procedure. Following a review of the existing QA methods, this paper will define a three-dimensional approach to the assessment of the educational aspects of an undergraduate course. Various features of this method will be described and potential benefits explained.

INTRODUCTION AND BACKGROUND

THERE ARE SEVERAL types of quality assurance (QA) systems being used by Higher Education Institutions (HEIs) in the UK, and all of them have some deficiency with regard to overall quality assessment.

- The Teaching Quality Assessment (TQA) system looks at teaching quality and related issues including pastoral care and vocational relevance [1]. It is focused on the questions 'How good is the management system?' and 'How good is the classroom teaching?' and adopts a peer review system.
- The Professional Institution Accreditation (PIA) examines the extent to which a programme prepares its students for the role of professional engineer. The programme environment and resources involved in the delivery of the programme are assessed by an examination of course outputs, it also adopts a peer review system.
- The Research Assessment Exercise (RAE) in the UK is focused on the quality of the research and the people and resources involved.

Each of these assessment patterns do not fully address the need to include the degree of subject understanding achieved by the student. Although programme completion rates are considered in TQAs they are coarse measures of student achievement. In the main they have an economic and managerial focus rather than an assessment of educational quality. Subject understanding is normally assumed to be related to final degree classification, typically through examination performance.

It has been proposed that success in subject understanding can be qualified by the concept of 'added value'. This is assumed to have a high score when a student arrives on a course with low entry qualifications and leaves the course with a high degree classification. Although this may infer that educational value has been added, this can only be confirmed when the relative standard of the Degree is compared to the output of other HEIs. The employability of the graduate is an important indicator included in the TQA.

The method of monitoring the quality of courses described in this paper has been based on the overall assessment of a student cohort. However the procedure could be applied to use the performance of individual students to monitor the quality of the course.

In the UK, at the present time, there is considerable government interest in ranking tables of academic institutions and the subject areas that they teach. However the methods of determining the relative difference between institutions and courses is simplistic and cannot accurately show the relative difference between undergraduate courses offered by different educational institutions, because it uses the methods described earlier. It is, therefore, of interest to examine the nature of the three quality assessment methods of course content, academic depth and amount of understanding. However, in order to place these assessment criteria in context the features of the different types of QA used by HEIs in the UK need to be described.

MODULAR UNDERGRADUATE PROGRAMMES

The recently established pattern of undergraduate programmes in the UK is largely

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based on a modular framework. This has some attractions, although the opportunity to use modularisation as a method to achieve large-scale revisions of established courses might have also been taken. There was, of course, no need for this to occur, since courses should be subject to continuous monitoring and review. In this respect the modularisation of courses provides the opportunity to:

- review programme pathways for multi-disciplinary departments/faculties;
- appraise teaching efficiency factors;
- achieve a balance of student effort for each module within the course.

However these advantages can complicate the assessment of the educational quality of a course or program. Where there are many course pathways there may also be many students with different backgrounds. It is, therefore, essential to plan effectively the prerequisite routes through the undergraduate programme. There should be a series of procedures that must be seen to operate effectively as a management system. Within an undergraduate programme where many pathways are provided there must be time between assessments for students and staff to make a reasoned decision about which pathway to follow. Where the decision time is limited there is a greater risk that the correct decision is not being made.

Teaching efficiency, in order to optimise resources, is an essential part of Higher Education. However, where large groups are taught there is also a need for tutorial/seminar back-up classes that must form part of any teaching efficiency calculation. The ability to reduce class contact time and thereby increase student-centred learning time is viewed by the higher education community at large as good. However, in order for this approach to be effective it should include a monitoring and assessment procedure that is individually focused and sensibly resourced. The cost of producing student-centred teaching material can be expensive although re-use brings this cost into perspective. Whilst it may be straightforward to provide factual information for this purpose, student-centred learning material is rather different [2]. In recent years more student-centred learning material has become available, particularly through the World-Wide-Web, e.g. http://ctiweb.cf.ac.uk/.

In addition there must be methods of monitoring student progress and this must be fed back to the student. This can be achieved, for example, by marking assessed or unassessed coursework and projects. This is straightforward where the work is completed by one student but more complicated when allocating assessments for group work. Indeed the ability to determine individual understanding from group work requires some form of individual assessment.

TQA issues

It is common practice to use the final degree classification of a student as a means of quantifying their level of understanding of the subject. This may be based on work in the final year or on work over the final two years of a programme. Since subjects are defined through the use of educational aims and objectives, or educational aims and learning outcomes and the final year subjects will include higher level objectives than those in previous years, direct comparisons are not straightforward. The addition of marks is a simple practical means of broadening the educational base of the degree but may not be educationally an addition of equals.

There are other issues that are relevant in the context of TQA, they include:

- Academic staff who are not education trained may incorporate educational weakness in the formulation of programme documentation. Where staff concentrate on subject content rather than educational objectives or learning outcomes, then unbalanced courses may result.
- Staff have special interests/subjects which they include in courses or flavour programmes. This offers many advantages although this content can be modified by PIA. It is essential that this flavouring addresses the educational quality issue from the student's perspective [3].
- TQA, whilst focusing on vocational relevance and graduate employability, does not specifically address the technical content of the course in relation to the needs of the graduate. This is assumed to come from either the HEIs or the PIA or both. Indeed it is seen as educationally sound to not include subject specialities as the managers of a visiting TQA panel.

PIA issues

This commonly considers a range of issues through a detailed examination of the course outputs. These outputs include:

- The visiting accreditation panel from the Professional Institution views the aims and objectives of the programme in relation to the vocational role or roles of the Professional Institution. This may not be a strictly educational view.
- Accreditation views innovation in relation to the needs of the profession rather than in terms of educational or vocational futures. Whilst this may influence the panel to take a traditional view there is always an opportunity for the HEI to explain their innovatory approach.
- The course content is commonly measured in detail usually by reference to professional institution guidelines; for example those developed by the Chartered Institute of Building [4]. There is no direct measure of teaching quality or student understanding, apart from reviewing student work and interviewing students. Examination papers are also reviewed in terms of subject coverage.

- The assessment of teaching quality should not be simplified into the number of corporate members of the accrediting professional institution involved in teaching the programme. The number of corporate members is important when considering the professional environment of the course. Corporate members should be aware of and involved in the key issues of concern to the profession.

RAE issues

The RAE does not concentrate on teaching quality, teaching resources or student understanding. This is because the RAE is focused on a range of other academic issues. These include:

- refereed publications;
- the quality and quantity of research output;
- the number of staff involved in research;
- the national and international research standing of the research staff.

Since the RAE critically appraises the ultimate academic discipline of a department it may also show the commercial links which can feed in specialist lecturers and resources into courses. It is well recognised that research activities can be used in undergraduate teaching, since it adds a unique flavour to the course. However this can only be given to students who can understand the subject and is commonly only offered to final year students. Undergraduate dissertations can have a research flavour or act as pilot/scoping studies into possible research areas.

PROGRAMME FEATURES IN THREE DIMENSIONS

In view of the different approaches to course quality, as described earlier, it is clear that there is a need to measure a range of quality features associated with undergraduate engineering courses. There is also a need to quantify their relative contributions. This paper proposes that these features can be represented in a three-dimensional way, as Fig. 1.

Course load

This is shown on the 'x' axis of Fig. 1 in hours where:

$$\text{Total Course Quantity Hours} = \text{Contact Hours} + \text{Student Study Hours}$$

This is a normal model for a modular course.

Academic content

This is shown on the 'y' axis. The levels of the educational objectives are weighted to quantify the axis. This weighting could follow the hierarchical order of the six different classes of educational objectives as proposed by Bloom *et al.* [5]. This would weight the objectives as:

1 for knowledge
2 for comprehension
3 for application
4 for analysis
5 for synthesis
6 for evaluation

The total value of the 'y' axis = number of objectives multiplied by their weighting.

This approach challenges the current assessment methodology that does not encourage the numerical comparison of educational differences. In individual courses there will inevitably be differences in academic content. Therefore in an overall programme there will be many differences in academic content. This is a fact and is encouraged through a whole range of processes involving the course team, the HEI and professional institutions. An engineering course is required to show an educational progression from the accumulation of knowledge to critical evaluation. Indeed in can be argued that the ability to carry out critical evaluation can only be successfully achieved by students who have sufficient knowledge of the subject.

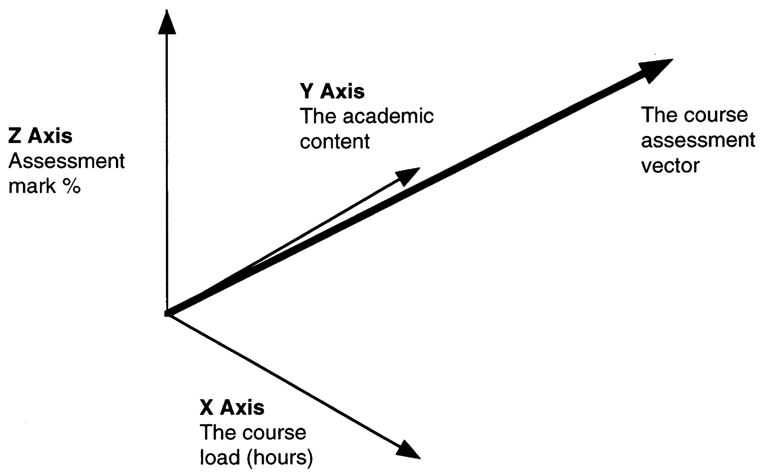

Fig. 1. Features of undergraduate courses shown in three dimensions.

Assessment marks

This is shown in Fig. 1 on the 'z' axis. The magnitude of the 'z' axis can be used as an indicator of the amount of the course that has been understood by the student. Full understanding of all the educational objectives would give a 100% assessment mark. In this way the effectiveness of the course in meeting the educational objectives can be assessed. This would include all of the results from the different assessment regimes used in the course.

Whilst it can be argued that the direct linkage between assessment marks and understanding is simplistic, it does provide an easily understood and available measure. In order to provide a true measure of understanding there should be no external influences on the assessment marks. This is difficult to ensure within an educational environment which appears to demand assessment averages within the 50% to 60% range. Whilst higher averages may indicate enhanced student understanding it can also indicate an undemanding course. Similarly, lower assessment averages can indicate opposite effects. Although these courses are more likely to produce student failures there can be positive benefits since a detailed review of the course is more likely when students fail or have pre-requisite choices reduced.

The interests of the institution and other vocational needs will influence the relative magnitude of the 'x' and 'y' axis. The quality of the course delivery and the nature of the student group will influence the magnitude of the 'z' axis. Using this notation a series of parameters can be defined, these include:

Stated course content $= \mathrm{S_{cc}}(x_1 \cdot y_1)$

Stated programme content = Spc

$$= (x_1 \cdot y_1) + (x_2 \cdot y_2) + \ldots (x_n \cdot y_n)$$

$$\mathrm{S_{pc}} = \sum_{1}^{n} S_{cc}$$

Educational course content

$$= \mathrm{E_{cc}} = (\mathrm{x_1 \cdot y_1 \cdot z_1})$$

Educational programme content

$$= \mathrm{E_{pc}} = (x_1 \cdot y_1 \cdot z_1) + (x_2 \cdot y_2 \cdot z_2) + \ldots (x_n \cdot y_n \cdot y_n)$$

$$\mathrm{E_{pc}} = \sum_{1}^{n} E_{cc}$$

where $\mathrm{x_1} = \mathrm{x}$ value for course 1, etc., $\mathrm{y_1} = \mathrm{y}$ value for course 1, etc., $\mathrm{z_1} = \mathrm{z}$ value for course 1, etc.

QUANTIFYING THE THREE DIMENSIONS OF COURSES

These parameters have the potential to show differences for each part of the course. These differences could be assessed in relation to the modular size of the course as agreed by the course team. An ideal module would have the **total course quantity hours**, all of the educational objectives would be met and all of the students would achieve 100% in the assessments. It is appreciated that this is unlikely to occur in practice. A more practical outcome can be shown by reference to an example of a course of one module size that has been taken by a group of students. The module has a total course load of 60 hours and an educational objective weighting of 44. The average assessment mark for the student group was 50%. It could be argued that this is an example of an acceptable course. From this data the values for the three axes are:

- x = *60 hours total course load.* This may vary depending on the actual **contact hours** and **student study hours** devoted to the course.
- y = *44 educational objective weighting.* This may also vary since, for a range of reasons, the course educational objectives were not met. It is reasonable to assume that the values on the 'x' and 'y' axis are directly related.
- z = *50% average assessment mark.* This may be obtained from a combination of coursework and examination marks. There are several issues to be considered with regard to the 'z' axis. It would be of interest to know the highest and lowest assessment mark, which together with the sample population would enable a range of statistical parameters to be determined. The difference between the highest and lowest assessment mark is a function of the variability of understanding of the course subject matter. Depending on the frequency distribution of the assessment marks it is also possible to determine the pass rate for a pass mark.

THE COURSE ASSESSMENT VECTOR

The three-dimensional approach, as shown on Fig. 1, allows the parameters of the course to be represented by a vector. The magnitude and direction of this vector is determined by the magnitudes of the three axes. However in order to determine the magnitude and direction of this vector the axis must have similar units. This can be obtained by expressing the magnitude of the axis as a percentage. Using the example, as above, then:

- x = 60 hours total student effort = 100%
- y = 44 educational objective weighting = 100%
- z = 50% average assessment mark = 50%

The resultant vector is shown on Fig. 2 and termed the **course assessment vector** (CAV). Applying this approach it is possible for a region to be identified which marks the boundary between an acceptable and ideal course. The ideal course would have a 100% value on each axis. This would give similar

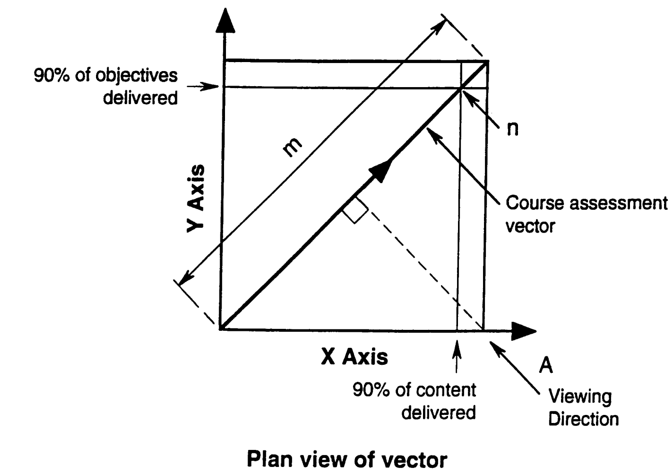

Fig. 2. Plan view of course assessment vector.

values for each axis and produce an **ideal course assessment vector** (ICAV), as shown on Fig. 3.

Taking a closer look at this vector and only considering the x-y plane then 'm', the plan length of the vector, is given by;

$$m = \sqrt{x^2 + y^2}$$

Taking a view perpendicular to the plane of the vector allows 'l_v', the true length of the vector, to be determined from;

$$l_v = \sqrt{x^2 + y^2 + z^2}$$

and 'θ', the angle of altitude of the vector, from;

$$\operatorname{Tan}\theta = \frac{z}{\sqrt{x^2 + y^2}}$$

From the earlier example where, $x = 1$; $y = 1$; $z = 0.5$, then $l_v = 1.5$ and $\theta = 19.47°$.

These features of the CAV can be used to describe the course. In this example should θ fall below 19.47° and the 'x' and 'y' coordinates stay the same then there is cause for concern since the average assessment mark has reduced. However this example can be compared to an ideal course, where the average assessment is 100%. In this case $l_v = 1.73$ and $\theta = 35.26°$. This defines the ideal course assessment vector (ICAV).

Attributes of the course assessment vector

The example shown previously made the assumption that all of the educational objectives and the total student effort hours had been achieved. It is reasonable to assume that for a real course the average assessment may be less than 100%. However, it is also reasonable to consider that there may be a reduction in the total student effort hours and a consequent reduction in the number of educational objectives achieved by the course. By applying reduction factors to the three-dimensional view of the ideal course, as shown in Fig. 3, the minimum acceptable CAV, or MCAV, can be drawn. The three-dimensional zone showing the difference between the minimum acceptable and the ideal course is shown in Fig. 4. In Fig. 2 it has been assumed that it is acceptable to report a reduction of 10% in the total student effort hours, and, due to the direct relationship between them, to also report a reduction of 10% in the number of educational objectives delivered. The lowest acceptable average

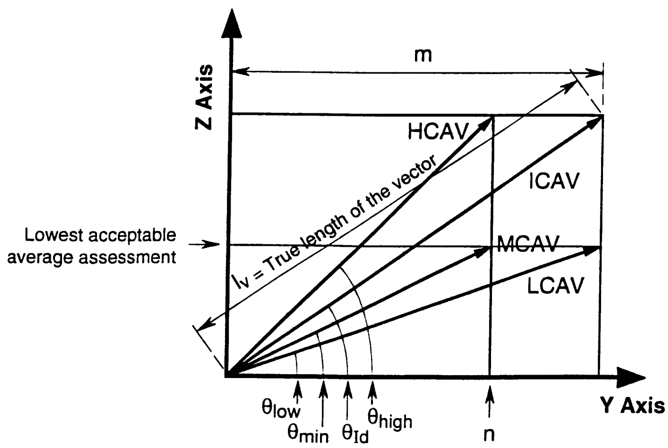

Fig. 3. View from direction A on Fig. 2.

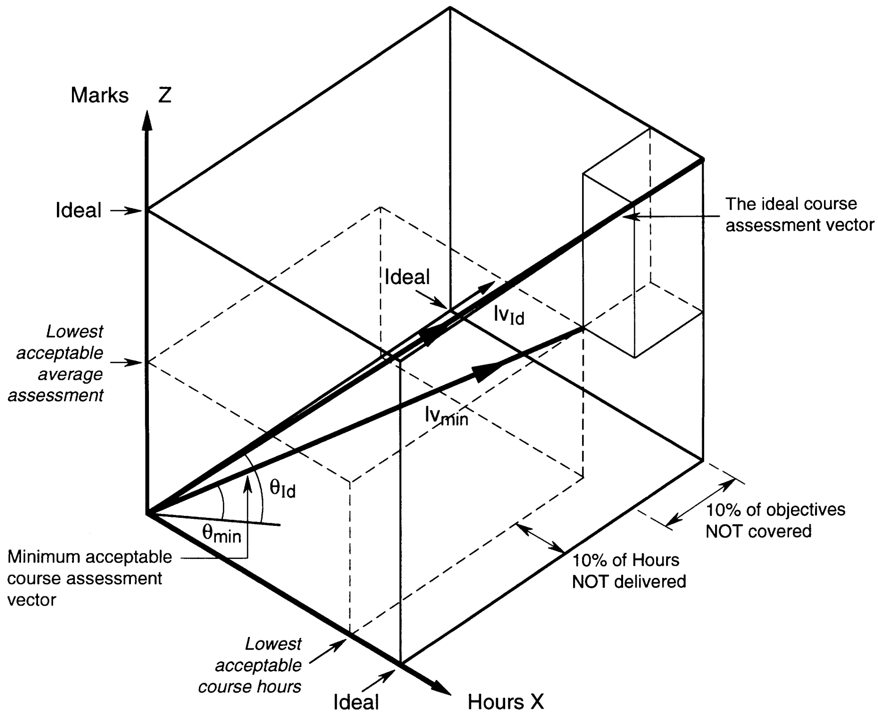

Fig. 4. Minimum acceptable and ideal course assessment vectors.

assessment has been assumed to be 50%, as earlier. Figure 5 therefore represents the target area into which an assessment vector must fall in order to meet the criteria as defined earlier.

In order to determine the boundary conditions of the vector, and using the notation shown in Fig. 1, then the horizontal plane bounded by coordinates:

$$[(x_{90}, y_{90}, z_{50}), (x_{100}, y_{90}, z_{50}),$$
$$(x_{100}, y_{100}, z_{50}), (x_{90}, y_{100}, z_{50})]$$

will produce:

(i) a vector length (l_v) where, $l_v \geq l_{vmin}$ where l_{vmin} is the true length of the MCAV;

(ii) an angle of altitude of the vector (θ) where $\theta \leq \theta_{min}$ where $_{min}$ is the angle of altitude of the MCAV

The horizontal plane bounded by coordinates:

$$[(x_{90}, y_{90}, z_{100}), (x_{100}, y_{90}, z_{100}),$$
$$(x_{100}, y_{100}, z_{100}), (x_{90}, y_{100}, z_{100})]$$

will produce:

(i) a vector length (l_v) where, $l_v \leq l_{vId}$where l_{vId} is the true length of the ICAV;

(ii) an angle of altitude of the vector (θ) where, $\theta \geq \theta_{Id}$ where $_{Id}$ is the angle of altitude of the ICAV.

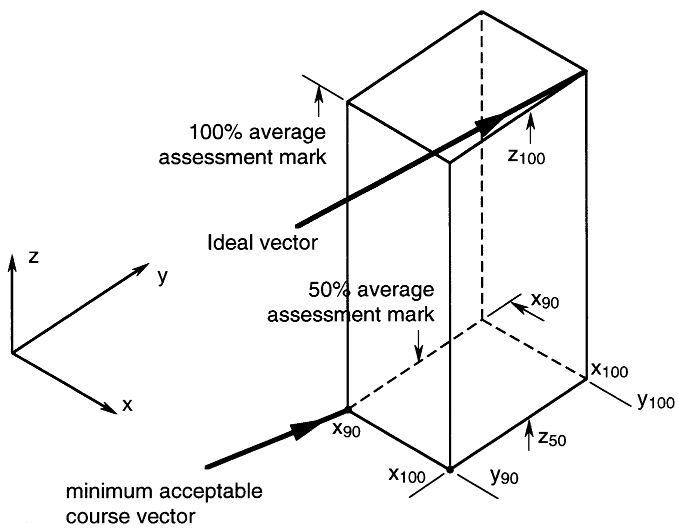

Fig. 5. Course assessment vectors target area.

In a similar way the coordinates of all of the planes defining the target area as shown in Fig. 5, can be determined.

The target area could be further modified to accommodate a range of conditions that are set by the course team. This may include, for example:

- All of the course content is delivered. Not less than 90% of the educational objectives have to be achieved and the average assessment must be not less then 50%. Then the plane of interest would then be bounded by coordinates:

$$[(x_{100}, y_{90}, z_{50}), (x_{100}, y_{100}, z_{50}), (x_{100}, y_{100}, z_{100}), (x_{100}, y_{90}, z_{100})]$$

or alternatively,

- Not less than 90% of the course content must be delivered, all of the educational objectives must be achieved and the average assessment must be not less than 50%. Then the plane of interest is bounded by coordinates:

$$[(x_{90}, y_{100}, z_{50}), (x_{100}, y_{100}, z_{50}), (x_{100}, y_{100}, z_{100}), (x_{90}, y_{100}, z_{100})]$$

Although vector lengths and angles could be determined for these conditions, the assessment of the course can be simplified by comparing the magnitudes of the x, y and z coordinates to those values set by the course team. Clearly any x or y coordinate less than 90% are a cause for concern.

For the example shown earlier and referring to Fig. 3, it is possible to consider the difference between θ_{Id} and θ_{min}. Because the ICAV and the MCAV are in the same plane it is possible to carry out a simple subtraction to obtain the difference between these angles. As the ICAV is in a fixed position relative to all possible variations in the position of the MCAV, it is the θ_{min} which should be moved into the plane of the ICAV when there is a difference between the relative values of the x and y coordinates. The example shown earlier assumed that both the x and y coordinates were reduced by the same amount to 90%. This is reasonable since the scaling of the course load, the x coordinate, can be assumed to be directly proportional to the academic content, the y coordinate.

When examining the plane of the ICAV and assuming equal reductions in the magnitudes of the x and y coordinates then a range of further conditions, as shown on Fig. 3, can be examined. These include:

- when $\theta \leq \theta_{min}$ but $\geq \theta_{low}$ then l_v must be $\geq$MCAV but $\leq$LCAV and the minimum average assessment values must be attained;
- where LCAV = the lowest course assessment vector;
- when $\theta \geq \theta_{Id}$ but $\leq \theta_{high}$ then l_v must be $\geq$HCAV;
- where HCAV = the highest course assessment vector;
- when $\theta \geq \theta_{min}$ but $\leq \theta_{high}$ then l_v must be $\geq$MCAV and the minimum average assessment value must be attained.

OVERALL COURSE ASSESSMENT

Using the methods described earlier all of the features of the course can be shown in a standard format. This could include the following.

Course load

Total course quantity hours (x_{total}). This would normally be available from the unit/module information sheet.

Actual course quantity hours (x_{actual}). This would normally available from course delivery information. The hours would not be more than those of the total course quantity hours. The maximum permitted difference ($x_{total} - x_{actual}$) can be determined by the course team.

Academic content

Total academic content of the course (y_{total}). This would normally be available from numerically weighting the educational objectives of the course. This is obtained from the unit/module information sheet.

Actual academic content of the course (y_{actual}). This would normally be available from course delivery information. The numeric weighting would not be more than those for the total academic depth of the course. The maximum permitted difference ($y_{total} - y_{actual}$) can be determined by the course team.

Assessment marks

This information gives some indication of the amount of understanding of the course content by the student and includes:

- the average mark of the student group;
- the maximum mark from within the student group;
- the minimum mark from within the student group;
- the standard deviation of the assessment marks of the student group;
- the pass mark.

All of the above assessment features can be used by the course team to monitor the operation of the course. However, using these and other criteria, the course team can determine the average mark for the student group. This can be represented as (z_{actual}) and compared to the highest possible average mark (z_{total}). The maximum permitted difference ($z_{total} - z_{actual}$) can be determined by the course team.

Vector information

The length of the ICAV, when based on percentages for the x, y and z coordinates, will always be 1.73, as earlier, and the angle θ_{Id} will always be 35.26°. When the actual data from the course

Institution Name:…………………………………………
Department /Faculty:……………………………………
Course Name/Code No.:…………………………………… Date ../../..
Course Leader/Convenor:…………………………………

Student Effort Hours	Ideal %		Actual %		Min. Accept.%		Diff.		Acceptable Y/N	
Educational Obj. Score	Ideal %		Actual %		Min. Accept.%		Diff.		Acceptable Y/N	

Assessment Marks	Ideal Av. %		Actual Av. %		Min. Acc. Av. %		Diff		

Assessment Marks	Min. %		Max. %		Stnd. Dev.		Pass Mrk %		Pass Rate %	

Stated Course Content		Educational Course Content	

HCAV	lv		Alt. Angle (H)	
ICAV	lv		Alt. Angle (I)	
MCAV	lv		Alt. Angle (M)	
LCAV	lv		Alt. Angle (L)	
Actual CAV	lv		Alt. Angle (A)	

General Criteria:
If $\theta_A \leq \theta_M$ but $\geq \theta_L$ then l_v must be $\geq$ MCAV and the minimum average assessment mark must be reached.
If $\theta_A \geq \theta_I$ but $\leq \theta_H$ then l_v must be $\geq$ HCAV
If $\theta_A \geq \theta_M$ but $\leq \theta_L$ then l_v must be $\geq$ MCAV and the minimum average assessment mark must be reached.

Fig. 6. Example of course assessment form.

delivery is available then all of the features described earlier can be determined. This can be shown using the example introduced earlier.

Overall course assessment example

The total student effort hours and all of the educational objectives of the course have been achieved. The average assessment mark is 50%. Therefore the following 'x', 'y' and 'z' coordinate values apply:

- $x_{actual} = 60$ hours total student effort $= 100\%$
- $y_{actual} = 44$ educational objective weighting $= 100\%$
- $z_{actual} = 50\%$ average assessment mark $= 50\%$

Then, $l_v = 1.5$ and $\theta = 19.47°$

The course team has agreed that as a minimum it would be acceptable to reduce the actual student effort hours and the educational objectives of the course to 90% of the total. This allows the actual results to be compared with the minimum acceptable course. This gives, assuming an average assessment mark of 50%, and making reference to Fig. 3, the following:

LCAV $= 1.50$ and $\theta_{low} = 19.47°$
MCAV $= 1.37$ and $\theta_{min} = 21.49°$
ICAV $= 1.73$ and $\theta_{Id} = 35.26°$
HCAV $= 1.62$ and $\theta_{high} = 38.22°$

When these results are compared to the actual results in the example, where $l_v = 1.5$ and $\theta = 19.47°$, then the actual results are acceptable since they are identical to the values for the LCAV and the θ_{low}. However it is useful to consider the difference between θ_{Id} and θ_{min}. In this example this is given by:

$$35.26° - 19.47° = 15.79°$$

This can be referred to as the degree of misunderstanding of the course. In this example it is a positive value although for cases where θ is $> \theta_{Id}$ then the value would be negative and therefore the difference $\theta_{Id} - \theta$ should be shown as a modulus as:

$$|\theta_{Id} - \theta|$$

All of these parameters can be included in a proforma, which is completed immediately after the course has been delivered. This would then allow any feedback from the students to be included. An example of a form is shown in Fig. 6, where it is clear that much of the information is obtained from existing course information.

CONCLUSIONS

The method described in this paper offers advantages over traditional monitoring and assessment techniques of undergraduate courses. All of the existing parameters of course monitoring and assessment have been retained but combined to produce an overall range of monitoring and assessment criteria.

Although the use of a vector to describe the relative quality of a course is unusual it offers the advantage of simplicity. The vector approach allows two numbers to describe the effects of three features of a course.

Consideration of the academic content of courses is of concern to all of those involved in undergraduate teaching. The method described here assumes that the course content can be specified in educational objective terms, whilst also raising the issue of how this can be accurately carried out. It is to be expected that in the early courses of a programme there would be a majority of educational objectives from Classes 1 and 2 of Bloom's Taxonomy [5], whilst in the later parts of courses objectives from Classes 5 and 6 would be included. If this method were adopted it would be possible to compare the academic content of different courses in a programme.

Further work to standardise the gathering of course data and to make the procedure available in electronic format, is progressing.

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