In defence of open-book engineering degree examinations

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Abstract In many faculties of engineering around the world, the current practice is to assess candidates by the closed-book mode of examination. However, in solving real-life problems, engineering practitioners may apply their knowledge either directly through recall of pertinent knowledge and experiences or, as is normal in most cases, by consultative reference. In the latter case, they elect to make use of whatever resources that may be available to them. The question we pose then is, 'Why do some engineering educators still insist on closed-book examinations?' This paper unveils the misconceptions while arguing in support of the open-book mode of examination. Towards that end, actual results from mechanical engineering degree courses in two universities in two countries are presented.

Keywords open book; engineering examinations; Botswana; New Zealand

Introduction

In engineering education there has been an ongoing controversy concerning closed-book (CB) and open-book (OB) examinations over the years. Engineering faculties based on the British system of education have tended to favour the CB examination. On the other hand, faculties of engineering based on the Continental European system of education have been more inclined towards the OB examination. As an example, the Faculty of Engineering at the University of Dar-es-Salaam, Tanzania – a university based on the British system – which was established in 1970 by the then West German government, began by assessing its engineering candidates by the OB examination mode, but later adopted the CB examination mode, which is still in use.

Some faculties of engineering in English-speaking countries have accepted both modes of examination, by allowing their staff to decide which is the best assessment mode for them. Accordingly, some staff examine their candidates by the OB mode. The Faculty of Engineering at the University of Canterbury in New Zealand is one example.

CB examination

In CB examinations, engineering candidates are not allowed to have within the examination room any material except their answer books, drawing equipment, and computational tools (calculators), the last of which are invariably supposed to be non-programmable. In the olden days, candidates had to memorize all the formulae they needed for the examination. Later on, examiners started to include some of the complicated formulae as part of the information given to candidates. The opponents of this CB mode of examination argue that it encourages the students to learn by rote, because they are expected to remember formulae and reproduce them at examination time. They also argue that this mode of examination does not reflect the real-life environment, where the engineering professional solves problems under OB conditions as he/she refers to technical books, manuals and various other resources, for example the Internet.

In addition, administering CB examinations to large classes entails a lot of human resources to ensure that no student comes to the examination room with unauthorized material. Furthermore, disciplinary committees have to be put in place to deal with those who manage to sneak into the examination rooms with such material and are discovered. Over the years, candidates have devised ingenious methods of accessing the material they want to have with them during examination time, so that it takes a vigilant invigilator to catch them. Cases of candidates hiding material in washrooms and accessing them when they are allowed to go there have been documented. In response, some university examination regulations now require that candidates must be escorted by invigilators when visiting the washrooms!

OB examination

In this paper, we define a fully OB examination as a form of examination into which the candidate may bring any material that he/she deems may assist him/her. The material may be in the form of, among other things, books, class notes, or information stored on diskette (in the case of computer-based examinations). Partial OB examinations are also practised. In such examinations, the candidates may be allowed to bring their class notes only, or may be asked to prepare and bring a summary of the course material not exceeding a specified number of pages. In this paper, any reference to an OB examination connotes the fully OB version. In OB examinations, the only thing to guard against is communication between candidates. Because of this, OB examinations are easier to invigilate than CB examinations.

Proponents of the OB examination argue that this mode approximates closely the environment in which the engineering practitioner works. So why not allow candidates to solve examination questions under the same conditions as they would in real life? In the OB examination, candidates will be expected to organize and interrelate their knowledge obtained from various sources and think of the best way to apply it to solve a particular problem. Assuming that the examination questions are well structured, only those candidates who fully understand the basic principles will be able to apply their knowledge. The emphasis then shifts away from rote learning towards an understanding that is motivated by potential application.

The University of Erlangen–Nürnberg in Bavaria, Germany, provides a lucid example. In the 1980s, every engineering student was expected to have the reference mathematical handbook *Taschenbuch der Mathematik* by Bronstein and Semendjajew [1]. This standard work on mathematics contains mathematical formulae, definitions and conceptual explanations, as well as illustrated examples of key but complex concepts, the recall of which would be expected only in an actual examination in mathematics. Hence those candidates who would sit for examinations in, for example, electromagnetic waves, engineering electrodynamics, or systems theory – all of which are highly mathematical in content – were allowed to refer to this book. This practice excluded the possibility that a candidate might fail an examination owing to his/her inability to recall complicated formulae, such as that for transforming a volume to a surface integral, or cylindrical coordinates to spherical coordinates. Instead, the examiner was assured that failure to pass a particular examination could be attributed to either the student's partial mastery of the course content or his/her inability to apply mathematical concepts in the solution of the problem at hand. OB examinations demand a lot of preparation on the part of both the examiner and the candidate taking the examination. From personal experience, candidates who are ill prepared for an OB examination simply fritter away precious time trying to find the relevant sources.

We would like to emphasize that setting questions for an OB examination is more demanding on the staff than for a CB examination. The questions have to be carefully chosen so that the average student who has attended all the classes and done all the assignments should be able to pass the examination by thinking through the solution. As with all examinations, to be fair to the candidates, the questions have to relate to what the lecturer has covered. But above all, and as with all other examinations at degree level, the main requirement of an OB examination must be that the candidates are able to build around what they know as they solve examination problems that are rich in all levels of testing, namely knowledge recall, comprehension, application, analysis, synthesis, and evaluation [2]. The setting of an OB examination taking into account the afore-mentioned elements is so demanding that this could be the primary reason why there is a prevalent opposition to OB examinations.

We have already argued that OB examinations can discourage rote learning. There are several other pedagogical arguments in favour of OB examinations being the preferred choice for assessing the abilities and skills of engineering degree students. Here we consider only four. First and foremost is the argument alluded to earlier, that OB examinations are taken under conditions akin to the environment in which practising engineers normally work. Secondly, OB examinations are adaptable to changing course content. It may be worth noting that, owing to current developments in technology, students are under increasing pressures to cope with multiple skills. In doing so, they cover not only the content initially prescribed for them at the curriculum design stage but also content that may rightly be called 'extraneous'. Such content in turn calls for additional allocation of time for its coverage. OB examinations can be adjusted to accommodate extra content and time requirements. The third argument relates to the selection of course content. Given that it is practically impossible for college academic timetables to be regularly readjusted in an attempt to accommodate extraneous content, a sifting mechanism must be used to eliminate irrelevant content from syllabi. It would seem imperative, from the point of view both of the efficiency of covering ever widening course content and of effective covering of such content, that the emphasis would have to shift away from recall-type content towards a content that focuses on applications. Mohanan [3, 4] rightly notes that this change of mind-set calls for parallel shifts in the styles of teaching and learning, and manifests itself in new goals of testing students' skills and abilities. He argues that OB examinations constitute the most suitable form of skills testing. The last pedagogical argument in support of OB examinations derives from the inevitability of mixed-mode teaching/learning strategies brought about by current experiences in eLearning and computer-mediated teaching. Universities are increasingly embracing the opportunities brought about by eLearning initiatives, in addition to the traditional lecture method. In engineering, for example, the use of computer packages for both learning and consultancy in industry is now widespread. Using such packages, students can be introduced quickly to higher levels of knowledge assimilation, notably analysis, synthesis and evaluation of a problem at hand. Language syntax recall, which was once so prominent in computer-related CB examinations, is now considered low-level knowledge testing and is relegated to dedicated debuggers that come bundled with the software program. Instead, students are required to apply and piece together various methods learnt to arrive at a solution. By their very nature, therefore, computer-based examinations are best set as OB examinations. That the trend among faculties of engineering today is towards the use of computers for students' learning is itself a strong pedagogical argument in favour of OB examinations.

Some opponents of OB examinations argue, for instance, that because candidates are allowed to carry anything to the examination room, they will score embarrassingly high marks by copying from books and class notes. As is shown in the next section, OB examination scores are not significantly different from those for CB examinations. In fact, experience has shown that properly set OB examinations tend to yield lower average marks than CB examinations. Any evidence of exceedingly high marks may serve as a hint to the shortcomings of the examiner in setting the OB examination to acceptable criteria. As alluded to earlier, other opponents of OB examinations think that the setting of them is too demanding for staff and that they may be too difficult for the students. We submit that this need not be the case if necessary commitments and preparations are made for such examinations. Some tips on OB examinations are now available on the Internet [5, 6]. Towards the end of this paper, we have included a section on how to set OB examinations, to assist those who have not been involved in setting such examinations.

Comparison of actual results of OB and CB examinations

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In this university, OB examinations are not allowed and a special disciplinary committee of Senate is in place to deal with candidates caught bringing unauthorized material to the examination rooms. Continuous assessment (CA) contributes to the final grade of the candidates. The CA consists of tests, homework assignments, and/or laboratory reports. In the Faculty of Engineering, some courses are without a formal university examination (UE) at the end of the year or semester, and are therefore assessed entirely on the aggregate CA mark. The lecturers are allowed to decide on the mode of examination for the CA component. Most of the lecturers opt for CB examination and a few for OB examination. A good number of such CA-based courses are computer-skills oriented. In these courses, the tests and assignments making up part of the aggregate CA mark are in fact all OB examinations. In all other courses, the ratio of the CA component to the UE component is either 1 : 3 or 1 : 1. A candidate's performance is shown at this university by the following letter grades: A = 80–100%; B = 70–79%; C = 60–69%; D = 50–59%, E = 40–49% (fail, supplementable); F = 0–39% (fail, unsupplementable). Thus a pass is grade D or higher.

Course UB1

Fig. 1 shows the distribution of letter grades of the actual results of the average of three CB tests (CBTs), the average of two OB tests (OBTs) as well as one CB UE for a one-semester jointly serviced course on thermodynamics, dynamics, and mechanical systems, offered by the Department of Mechanical Engineering to 38 second-year candidates in the Department of Electrical Engineering at the Faculty of Engineering, which we shall refer to as Course UB1. The thermodynamics component was taught by one lecturer for half the semester with one CBT test and some homework assignments given during that period. Another lecturer taught the dynamics part in the second half of the semester and conducted two OBTs and some assignments. A third lecturer taught the mechanical systems part for the full semester of 14 weeks, giving two CBTs and homework assignments in the process. A combined CB UE was done at the end of the semester.

The three CBTs had an average mark ranging from 60% to 63%, which is a C grade. The two OBTs had a lower range of average mark, of 51% and 56%, which is a D grade. The final UE had an average mark of 62%, which is a C grade. The distribution of the letter grades for the 38 candidates for the average of the three CBTs, with an average C grade at 61%, is shown in Fig. 1(a). The average of the two OBTs, with an average D grade at 53%, is shown in Fig. 1(b). The distribution of the results of the CB UE is shown Fig. 1(c) and the average grade was C, at 62%. From these results it can be seen that there were fewer students who passed the OBTs than passed the CBTs or CB UE.

Fig. 1(d) plots the individual marks for each of the 38 candidates for the average of the three CBTs and for the average of the two OBTs. From these graphs it can be seen that the students who did very well in the OBTs also did well in the CBTs, whereas the reverse was not necessarily true. For example, candidate 22 had an average of 81% in the CBTs but an average of only 31% in the OBTs.

Fig. 1(e) plots the individual marks for each of the 38 candidates for the average of the three CBTs and for the CB UE. It can be seen that the students who did well in the CBTs also did well in the CB UE and vice versa, thus indicating a good correlation between the two results.

Fig. 1(f) plots the individual marks for each of the 38 candidates for the average of the two OBTs and for the CB UE. From these graphs it can be seen that the students who did well in the OBTs also did well in the CB UE, whereas the reverse is not necessarily true. For example, candidate 10 had a score of 82% in the CB UE

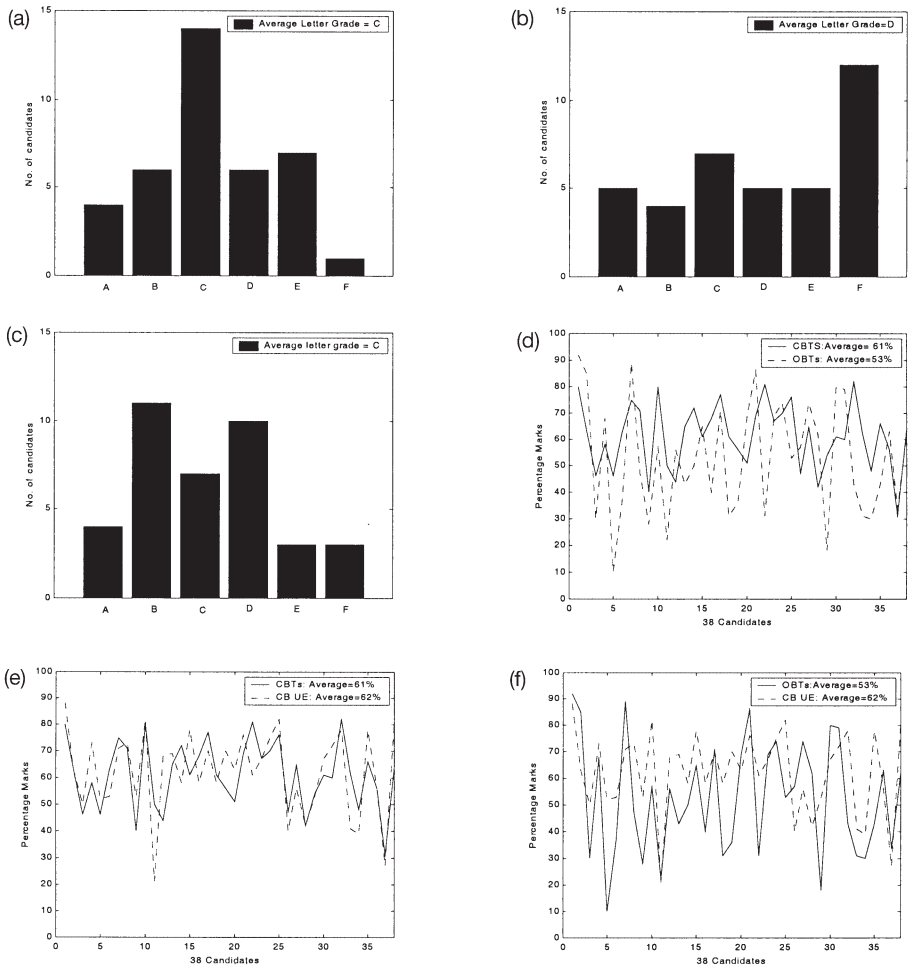

Fig. 1 *(a) Course UB1: grade distribution of average of three CBTs. (b) Course UB1: grade distribution of average of two OBTs. (c) Course UB1: grade distribution of CB UE. (d) Course UB1: Correlation of CBTs and OBTs. (e) Course UB1: Correlation of CBTs and CB UE. (f) Course UB1: Correlation of OBTs and CB UE.*

but an average of 57% in the OBTs, and candidates 32 and 35 both had 78% in the CB UE but an average of 43% in the OBTs.

It is therefore clear from the results of this course that OB examinations do not necessarily result in high average marks, counter to the claim that they allow students to achieve high scores too easily. Moreover, the proponents of CB examinations should note that, sometimes, CB examinations can produce some doubtful results. For example, candidate 22 mentioned above had an average of 81% in the three CBTs and therefore appears to be an 'A' student, whereas the same candidate scored an average of only 31% in the two OBTs, indicating that the candidate is actually a poor student; this was confirmed by the candidate's result of 61% in the CB UE, which is at the bottom of the range for a C grade.

It is interesting to note that, of the 21 candidates who passed the two OBTs, only three of them failed the three CBTs and none of them failed the CB UE. On the other hand, of the 30 candidates who passed the three CBTs, 12 of them failed the OBTs and two of them failed the CB UE.

Course UB2

Fig. 2 shows the distribution of letter grades of the actual results of the average of two CBTs, the average of three OBTs, and one CB UE for a year-long course on dynamics/solid mechanics, in the Department of Mechanical Engineering, which we shall call Course UB2. One lecturer taught the dynamics part in the first semester and conducted the two CBTs, whereas another lecturer taught the solid mechanics part in the second semester and set the three OBTs. A combined CB UE was done at the end of the year. The class was small, with only 12 candidates.

From the results of this course, the two CBTs have an average mark of 50% and 57%, and the three OBTs have a lower range of average mark, from 39% to 58%. The final CB UE had an average mark of 50%, which is a D grade. The distribution of the letter grades for the 12 candidates for the average of the two CBTs, with an average D grade at 54%, is shown in Fig. 2(a). The average of the three OBTs, with an average E grade at 48%, is shown in Fig. 2(b). The distribution of the results of the CB UE, with an average D grade at 50%, is shown Fig. 2(c).

Fig. 2(d) plots the individual marks for each of the 12 candidates for the average of the two CBTs and for the average of the three OBTs. Apart from the first candidate, there is good correlation between the two sets of results. Fig. 2(e) plots the individual marks for each of the 12 candidates for the average of the two CBTs and for the CB UE. Again, the graphs show good correlation between the two sets of results. Fig. 1(f) plots the individual marks for each of the 12 candidates for the average of the three OBTs and for the CB UE. Again, the graphs show good correlation between the two sets of results, apart from for the first candidate.

From the average of the CBTs and OBTs it is interesting to note that of the seven candidates who passed the OBTs, none failed the CBTs and only three failed the CB UE. On the other hand, of the nine candidates who passed the CBTs two of them failed the OBTs and four of them failed the CB UE at the end of the year.

Once again, the results of this course show no evidence of high average marks from OB examination.

Course UB3

Fig. 3 shows the distribution of the average letter grades of the actual results from four OBTs for a third-year one-semester course on computer applications, in the Department of Mechanical Engineering, referred to here as Course UB3. The course had two parts, which were taught by two lecturers for a period of seven weeks, to

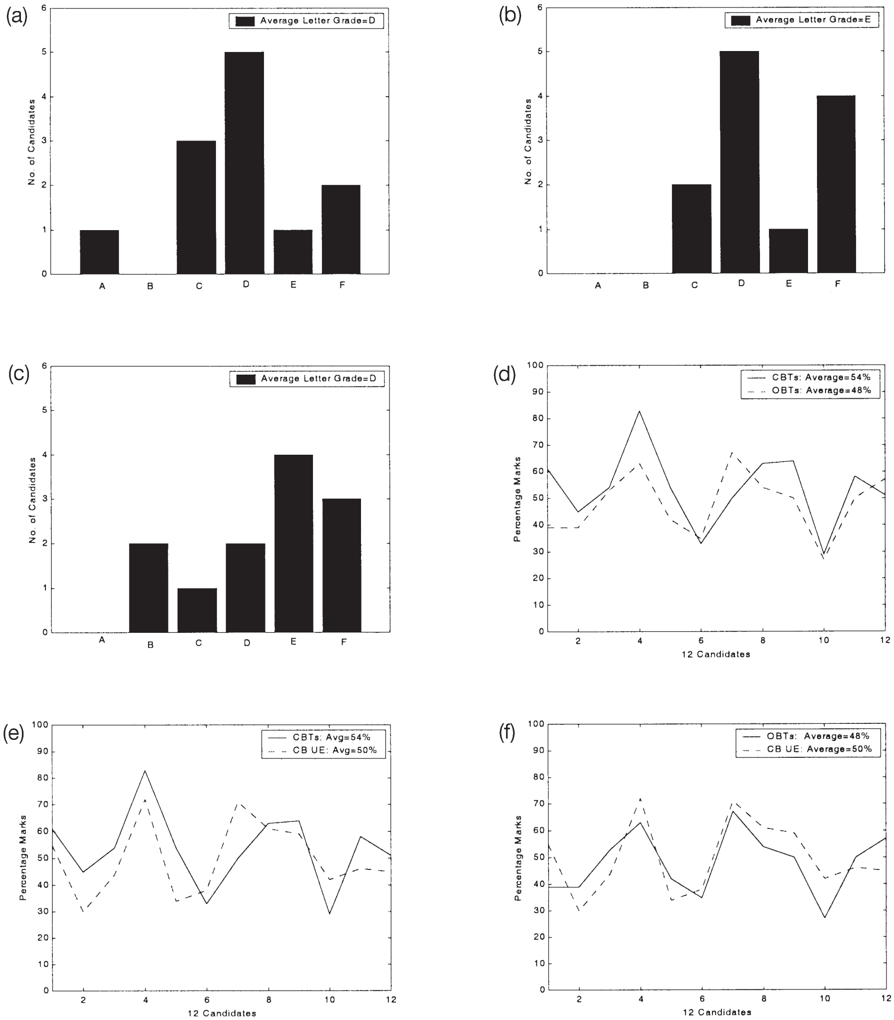

Fig. 2 *(a) Course UB2: average grade distribution of two CBTs. (b) Course UB2: average grade distribution of three OBTs. (c) Course UB2: Grade Distribution of CB UE. (d) Course UB2: correlation of average CBTs and OBTs. (e) Course UB2: correlation of average of CBTs and CB UE. (f) Course OB2: correlation of average OBTs and CB UE.*

the same candidates as in Course UB2. Each lecturer conducted two computer-based OBTs. The average in the four tests ranged from 62% to 70% and the average of the four CATs had an average of 67%, which is a C grade. This course is assessed by 100% CA and, therefore, the average of the four CATs represents the final grade of the course. The distributions of the letter grades for the four individual OBTs are shown in Fig. 3(a)–(d). Fig. 3(e) shows the average of the four OBTs. These results

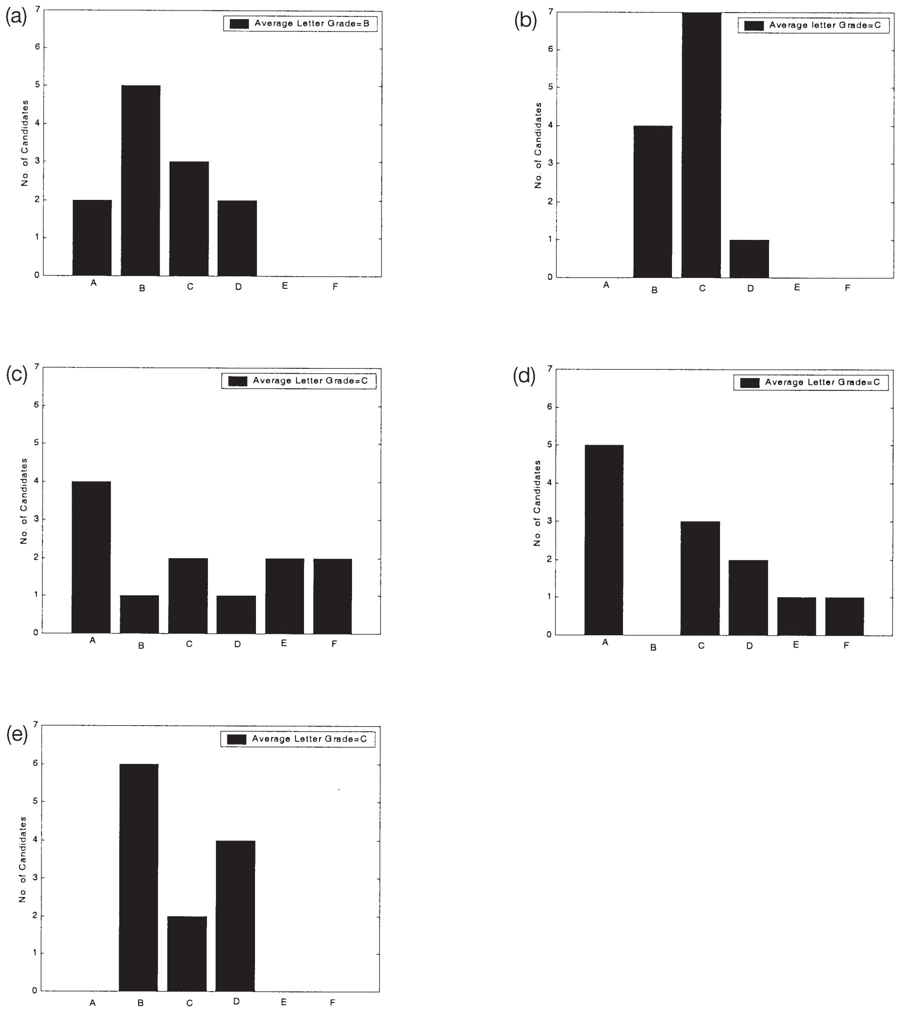

Fig. 3 *(a) Course UB3: grade distribution of OBT1. (b) Course UB3: grade distribution OBT2. (c) Course UB3: grade distribution of OBT3. (d) Course UB3: grade distribution of OBT4. (e) Course UB3: grade distribution of average of average of four OBTs.*

show that even for a course that is assessed entirely by CAT, OBT does not yield unusually high marks.

University of Canterbury, New Zealand

In this university, the lecturers are allowed to decide on the mode of assessment in both the CAT and UE. Therefore, some of them opt for CB examination and some for the OB examination. Also, CAT contributes to the final grade of the candidates.

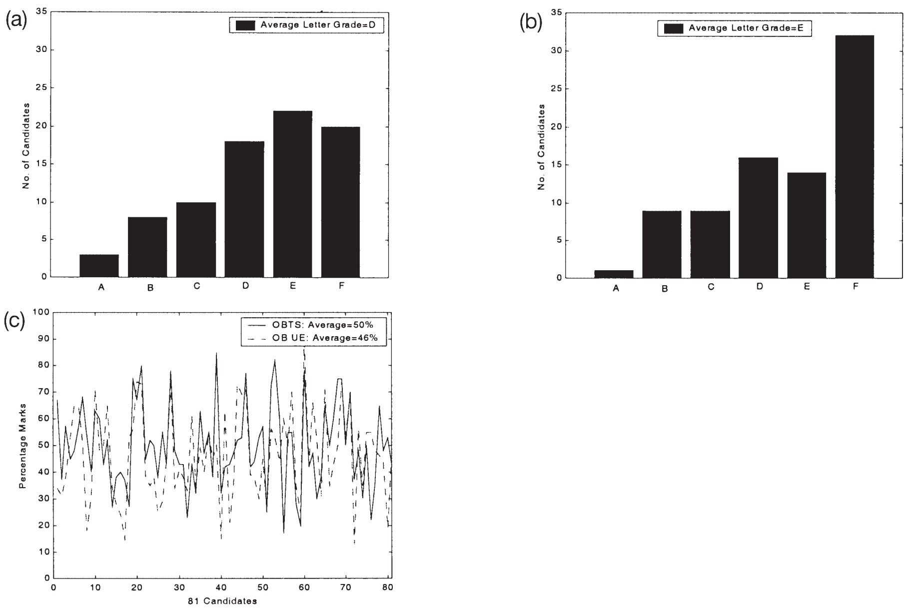

Fig. 4 *(a) Course UC: grade distribution of average of three OBTs. (b) Course UC: grade distribution of CB UE. (c) Course UC: correlation between OBTs and OB UE.*

In the Faculty of Engineering, a few of the lecturers have assessed the candidates by OBT in both the CAT and UE for many years.

Course UC

Fig. 4(a) shows the distribution of the actual letter grades of the average of three OBTs, while Fig. 4(b) shows the distribution of the grades for one OB UE for a one-semester course on solid mechanics taught to 81 second-year candidates in the Department of Mechanical Engineering. One lecturer taught the first part of the course during the first half of the semester, administering two OBTs in the process. Another lecturer taught the remaining part of the course in the second half of the semester, and gave one OBT. A combined OB UE was done at the end of the semester.

It can be deduced from the raw results for this course, shown in Fig. 4(a) and (b), that the average mark ranges from 38% to 61% in the three OBTs, while the final OB UE has an average mark of 46%. The average of the three OBTs is a D grade, at 50%, which is close to the OB UE average D grade, at 46%. It can also be seen from Fig. 4 that the performance of the class in the OBTs is about the same as in the OB UE. The class performed poorly in both the OBTs and the OB UE. From the raw results, of the 39 candidates who passed the three OBTs, 13 of them failed the UE. By comparison, of the 35 candidates who passed the UE, 11 failed the three OBTs.

Fig. 4(c) plots the individual marks for each of the 81 candidates for the average of the three OBTs and for the OB UE. In general there is good correlation between the two sets of results. The average is about the same for both. Of the candidates who did very well in the OBTs (over 70%), only two of them (candidates 29 and 65) did rather poorly in the OB UE.

Again, these results show that for a course which is assessed entirely by OBTs and OB UE, the overall OB results do not yield unusually high marks.

Current relevance of OB examinations

Current university education faces three broad challenges. From a demographic viewpoint, there is an increased demand on tertiary education to include more students from hitherto disadvantaged population sectors. Such a demand stretches the resources for managing examinations conducted on a CB basis. The second challenge is a financial one. Universities worldwide are contemplating methods of cost-minimization and self-generation of funds amid reduced government sponsorship. CB examinations introduce an additional cost to universities. This cost is proportional to the number of candidates. Finally, from the viewpoint of course content and dictated by rapid changes in technology, current university education is challenged to squeeze much more content into their curricula. Correspondingly efficient methods of learning and teaching are called for. In the not too distant future, dedicated computer workstations at which examinations are taken will replace the open examination hall. Computer-based courses are best examined by the OB examination mode to promote not recall but application of knowledge.

How to set questions for OB examinations

Before we give brief ideas on how to set questions for OB examinations, the lecturer's willingness to change to an interactive mode of teaching is presumed. The Interactive Workshop Method of teaching [3] gives lecturers a guide to the interactive mode of teaching. In engineering this can be done, for example, by merging the lecture and tutorial sessions, so that application problems related to the current lecture topic can be done jointly and interactively by the lecturer and students. In such sessions, the lecturer can start to train the students on thinking processes that are involved in OB examinations.

From our experience, an effective way of setting an OB examination question is to guide the student through the solution step by step. This can be done by making such a question multi-tiered, with several parts, each leading from one part to the other. The student is expected to know where and how to find the content information (which, of course, should have been covered by the lecturer) needed along the way for the solution of the particular question. A detailed marking scheme for each question should award marks for the various parts of the question.

The length of an OB examination need not be different from that of a CB examination. However, the important thing is that the questions for OB examination have to be more carefully thought out and more adaptable to changing content and the duration of such content.

In the Appendix, we have given two typical OB questions, one from mechanical engineering and the other from electrical engineering. For example, in part (a) of question A.1, the student is expected to know that a rotating loaded beam is subjected to fluctuating normal stresses. For part (i), the student is also expected to know (or find out) that a simply supported light beam carrying a point load at mid-span has a maximum bending moment there of $FL/4$. For part (ii) he/she is expected to know the application of a factor of safety to obtain the design stress, which will be used as the maximum stress in the formula

$$\sigma_{\max} = \frac{M_{\max} y_{\max}}{I}$$

$$\text{where} \quad y_{\max} = \frac{d}{2} \quad \text{and} \quad I = \frac{\pi d^4}{64}$$

where d is the diameter of the shaft, which is the required answer.

In part (b) of the question, the student is expected to know that a component carrying fluctuating stress can in addition carry a mean stress and that such a component is designed by empirical fatigue criteria formulae, such as the Modified Goodman or Gerber, which the student can find out (without having had to memorized them), and quickly draw them on graph paper. In part (c) of the question, the student is expected to be able to determine the maximum allowable value of F, using parts (a) and (b).

If the question were a CB examination question, the student would be expected to have memorized all the necessary formulae, which is unnecessary; alternatively, such formulae would have to be given as additional information, thereby denying the student the skill to find out such information on his/her own, which is what happens in real-life practice.

Part (a) of the electrical engineering example, A.2, tests the student's ability to distinguish between DC and AC signals on the basis of frequency. He/she is expected to relate that DC signals are signals with zero frequency, whereas AC signals are signals at a certain value of frequency and that the reactance is directly proportional to that frequency. Hence for a DC signal the reactance causes no opposition to current, a fact which is tantamount to short-circuit behaviour.

In part (b), the student is expected to relate the conclusion in part (a) to a circuit containing a DC signal source. The circuit reactance is thus zero. Ohm's law then gives $R = 10\,\Omega$.

In the next part of the question, with a 140 V, AC source at a frequency of 40 Hz, the student ought to relate that, in this case, both the resistance and the reactance constitute the combined opposition to the alternating current. Hence, using Ohm's law and a circuit current of 2 A, the student calculates the impedance, Z, of the circuit to be $70\,\Omega$. However, the student is able to state the impedance of this AC circuit using the following alternative expression:

$$Z = R + j2\pi fL$$

Hence, equating the magnitudes of the impedance expressed in the two forms, and substituting the values of R and f, the student is able to calculate the value of L, from

$$\sqrt{(R^2+(2\pi fL))^2} == \sqrt{(10^2+(2\pi fL))^2} = 70^2$$

$$L = 0.276\,\text{H}.$$

In the final part, the student now knows the values of R and L and is given a new magnitude of the AC voltage at a new frequency $f = 50\,\text{Hz}$. He/she is therefore able to determine the new value of the circuit impedance as:

$$Z = (10 + j2\pi 50 \times 0.276)\Omega = (10 + j86.6)\Omega = 87.18\angle 83.4°\Omega$$

Hence, applying Ohm's law again, the student can determine the current drawn from the supply as:

$$i = \frac{230\angle 0°}{87.18\angle 83.4°} = 2.64\angle -83.4°\text{A}$$

As in the mechanical example above, the student would not be expected to recall any of the formulae used in the solution, since the equations would be available to the student from the resource materials brought by the student into the OB examination.

Conclusions

We can make the following conclusions:

- OB examinations do not necessarily yield high marks.
- OB examinations demand of the examiner more thought and skill in the formulation of questions.
- OB examinations approximate a method of problem solution akin to that used in real-life engineering practice.
- OB examinations in engineering test the candidates' thinking process at all levels of knowledge, from basic recall to the highest level, involving application and interrelation.
- Results from OB examinations tend to produce lower average marks than do CB examinations.
- OB examination is easier to invigilate than CB examination.
- OB examinations may discourage the temptation of students to resort to rote learning.
- OB examinations exclude extraneous factors (recall of formulae etc.) that may unnecessarily influence the result of an examination.
- CB examinations require more resources.

Recommendations

Finally, we would like to make a cautious recommendation. Where the calibre of the academic staff and their commitment to the teaching function can be ensured, OB examinations can be adopted as the standard mode of assessment. One way of guaranteeing staff commitment could be through organized continuing professional development courses aimed at imparting the skills for OB examination design. However, where staff reluctance to adopt the new mode of examination is marked, flexibility should be encouraged. It would be better to start off with a few pilot courses headed by committed staff, rather than to seek the involvement of a large number of staff who might seek high student marks as a means to justify their initial aversion. Whereas the controversy over OB examinations as an alternative to CB examinations has been around for quite some time now, its relevance and place in today's university engineering education has never been more crucial. We recommend OB examinations with the above precaution so that, once embarked on, its full potential may be demonstrable. OB examinations certainly do not deserve the resistance to change that educators normally place on any novel thinking.

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Appendix. Examples of suitable OB examination questions

A.1 Example from mechanical engineering

(a) A light mild steel shaft is simply supported at the ends by self-aligning frictionless bearings. The length of the shaft between the bearings is 500 mm. The shaft rotates freely in the supports while carrying a downward point load of 16 kN at mid-span. The fatigue limit for mild steel of infinite life is known to be ± 195 MPa.

(i) Neglecting dynamic forces, determine the maximum of the fluctuating moment in the beam, and hence

(ii) Using a design stress safety factor of 3 based on the fatigue limit, determine a suitable safe diameter for the shaft, in millimetres.

(b) On the graph paper provided, accurately plot together the Modified Goodman and Gerber fatigue failure criteria graphs for mild steel whose yield stress, s_y, is 280 MPa, ultimate tensile stress, s_{uts}, is 460 MPa, and fatigue limit s_{fl} is 195 MPa. For the Gerber criteria graph, use four intermediate points between end-points as follows: $s_m = 0.2s_{uts}$; $s_m = 0.4s_{uts}$; $s_m = 0.6s_{uts}$; and $s_m = 0.8s_{uts}$.

(c) The shaft you designed in (a) above is now to carry an axial force, F, throughout its length, in addition to the same transverse load. Use the graphs you obtained in (b) above to determine the maximum allowable values of F in accordance to the Modified Goodman and Gerber fatigue criteria. Which of these two values would you recommend and why?

A.2 Example from electrical engineering

(a) Based on its value of frequency, infer the behaviour of an inductive reactance connected to a DC voltage source.

(b) The potential difference measured across a coil is 20 V when a direct current of 2 A is passed through it. When, instead of the direct current, an alternating current of 2 A at a frequency of 40 Hz is passed, the potential difference across the coil was found to be 140 V.

(i) Calculate the value of the resistance of the coil.
(ii) Calculate the value of the inductance of the coil.
(iii) If the coil is connected to a 230 V, 50 Hz supply, calculate the current drawn from the supply.