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Evaluation of software tools for formative assessment of control topics

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Abstract: This paper discusses some of the reasons for and consequences of changing assessment types away from traditional paper based exams. More specifically, consideration is given to the quiz environments available on virtual learning environments. Of particular interest to the reader are two core aspects: (i) the authenticity of the assessment for holistic assessment and (ii) managing student expectations of the process. The latter of these is the most challenging.

Keywords: Automated assessment, software tools in control, student expectations.

1. INTRODUCTION

Beginning from the early 1990s there has been a growing use of computers to assist in assessment of core learning outcomes. Within the UK this was led strongly by the mathematics community (MATHCENTRE, 2017; SIGMA, 2017; STACK, 2017) perhaps because the nature of the assessment lent itself to questions that were relatively simple to code, even on early quiz engines. Evaluation of the use of these tools, in the main, demonstrated that they were popular with both students and staff (Sim et al., 2004; Croft et al., 2001; Lawson, 1995; Rossiter et al., 2005). Perhaps the most obvious benefits were twofold:

- (1) Marking was automatic and thus staff could mark weekly student homeworks instantaneously and thus provide formative feedback that was not available through hand marking; certainly with large classes.
- (2) Students are able to self-test their progress and moreover, receive instantaneous feedback on their attempts. It is easy to ensure students get different questions and variable values each time to reduce collusion and encourage actual understanding.

Perhaps unsurprisingly, these initiatives are now also widespread in schools where teachers and students can obtain similar benefits (MYMATHS, 2017) and homework becomes an opportunity to redo a set of questions (with changing numbers and details each time), until pupils were confident in the topic and gained full marks.

1.1 Adoption of quiz engines in control engineering assessment

Having been exposed to the use of quizzes by the mathematics community, the author undertook several projects to trial their adoption into more mainstream engineering (e.g. Rossiter et al. (2004, 2005, 2006, 2007,b, 2018)). Indeed authors elsewhere within the control community have undertaken similar projects, but influenced by the software tools available to them ((Farias et al., 2016; Munoz et al., 2012)). Unsurprisingly, the early results were largely very positive and students appreciated what was relatively

novel and helpful at that time. Indeed, there is strong anecdotal evidence that students continue to appreciate the availability of such self-test tools although modern students are much more demanding about professional these environments should be; something most academic staff do not have the time and resource to manage alone.

The author has used the quizzes in a number of different modes ranging from solely formative to relatively high value summative and rather worryingly, found the student response to these different modes somewhat inconsistent and unpredictable. In the main, a core advantage of quizzes is their 24/7 availability on the web, but with this comes the increasingly likelihood that some students will collude. The author makes use of *question sets*, so if a quiz has say 10 questions, each of those 10 questions would be selected from a set of questions of equivalent difficulty and topic thus ensuring that in general, students sat side-by-side will get different questions. Where possible, questions will also have variables so that the numbers would differ even when they get the same question as a colleague although some students do complain that getting different questions could be considered as unfair. Some obvious dilemmas:

- If the quizzes are solely formative/optional, the majority of students do not use them. The fact that they could be helpful is not enough of a motivating factor.
- If regular small quizzes have a small ‘summative’ value to encourage engagement, students will do them but tend to be slightly less happy as the regular deadlines and requirement to keep up causes stress and a perception of having to work harder than on other modules. This is exaggerated by the fact that even for a 2% quiz, a minority of students complain about whether they have got 55 or 60 because of some confusion over a question, putting a decimal point in the wrong place and so on. Indeed, even for questions worth about 0.2% of a module, some students will complain that they get no credit for their working!
- If there is just one larger summative quiz towards the end of term, students tend to leave preparation to the last minute, thus undermining the potential

benefits of any formative quizzes for aiding and scaffolding learning. Complaints about getting no credit for working may increase in this scenario.

- The most popular approach seems to be one of fixed bonuses for meaningful engagement which is defined as getting a good mark on the quiz but by now means 90-100%, thus reducing the pressure to give your very best every week or so. This is likely to be the model most used by the author in the future.

Nevertheless, it should be reiterated that with an increasing number of classes with 300+ students, there is no realistic alternative which will allow students to assess their progress. Handmarking of regular homeworks is not possible with large numbers. The author offers weekly drop-in tutorials for individualised face to face help and guidance where required as this is focussed and efficient.

1.2 Generic obstacles to the use of quiz engines

Of course, there are some downsides to the use of computer quizzes. For example, the effort in creating a database of questions may be substantial, but once this has been achieved, the database can be re-used for many years, especially for topics which change slowly. Again, this issue was tackled effectively by the mathematics community for who sharing of questions nationally was not an obstacle, but a more pressing obstacle in fact turns out to be software. You can only make use of the databases available if your institution has the license to and/or supports the relevant software. Unfortunately, as yet there is no global standard on syntax so a database created in one software is unlikely to be easily transferable to another.

However, the most significant obstacle is student complaints about getting no credit for their working. The majority of quiz engines available in a university environment (for example the author's institution has only Blackboard (2018)) only support limited question types such as:

- Multi-answer and/or multi-choice. [This question has no variables so is fixed]
- Yes/No or true/false. [This question has no variables so is fixed]
- Calculated questions with a fixed numerical answer. [This question has no variables so is fixed]
- Calculated questions with some variables and an answer defined by a single formulae. [This question is fixed, but variable values can change.]
- Some other types using pictures, matching and so forth. [This question has no variables so is fixed]

The reader may notice immediately the consequence of these limited question types. The most significant obstacle is that you cannot have a numerical question with a part a,b,c, etc unless it has no variables as a later question cannot inherit a variable from a previous question. Hence, if you want question dependency, which is typical when building up a scenario, the questions must have predefined values and thus, EVERY student will get identical questions which increases the opportunity for inevitable collusion unless the quiz is taken under examination conditions. The author is aware that MAPLE tools (MAPLESOFT, 2018) amongst others, may resolve this limitation, but currently his institution does not have a license for that

software and moreover, readers should not underestimate the potential additional administration burden if the quiz engine is not linked in properly to the virtual learning environment; ad hoc or personally managed solutions are not something to be encouraged.

1.3 Summary and proposal

In general terms students appreciate the use of computer quizzes for formative learning, although they need incentives to engage. However, there is not much evidence of their use for assessment of large parts of a module most likely because of the obstacles: (i) computer room availability for large classes; (ii) a perception by both staff and students that written exams allow effective assessment of student working and (iii) concerns about collusion.

This paper seeks to investigate the latter of these two claims and asks the question:

Is there reason to believe that a computer assessment can be as authentic in assessing student ability as a written examination?

The author will make the argument that albeit the assessment is different, it would be difficult to argue that a paper based submission delivers a fairer or more accurate mark than a computer one for some learning outcomes. A natural consequence of this is to adopt computer assessment where the learning outcomes make this appropriate. This paper focuses on control topics (Rossiter et al., 2008, 2018) which are often quite mathematical, but naturally the principles can be applied more widely in engineering.

2. ARGUMENTS FOR AND AGAINST FAIRNESS OF TRADITIONAL END OF YEAR EXAMINATIONS

A core point to be made is that balanced assessment of student learning must inevitably involve a variety of assessment types in order to assess different skills and learning. This paper assumes this at the outset and instead focuses on what is the most efficient and reliable assessment for **specific numeric/mathematical skills** that are related to control engineering. Problem solving, communication, writing and other such skills are currently harder to assess automatically via a computer and thus those skills must be captured by alternative assignments. Nevertheless, it is accepted that for many engineering topics, a core assessment requirement is of the students' ability to perform set calculations accurately. Nested in with this maybe the selection of an appropriate algorithm or approach so that the calculation to be assessed implicitly also assesses student understanding of the context.

2.1 Quality assurance

A core requirement for University assessment is rigorous quality assurance procedures. It is a requirement to demonstrate clearly:

- It is transparent to the student what is expected of them. Wording and presentation is checked in advance by independent auditors.
- The marking schemes must be carefully defined to ensure consistency of treatment of students.

- Expectations are consistent with parallel assessments for the peer group, departmentally and nationally.
- After marking, all scripts are checked by an independent person. In some institutions and/or for some assignments, checking may include double marking.
- The assessment allows students to demonstrate ability across a full range of performance levels.
- The time taken for a typical student to complete the assessment is significantly less than the time limit provided so that the focus is on student competence rather than being a race.
- The assessments cover a broad range of the required learning outcomes (this is needed for accreditation).

2.2 Conflicts between quality assurance and paper based examinations

Any academic who has undertaken a substantial amount of marking of paper based examinations will be well aware of the numerous weaknesses of the system, especially when marking large numbers of scripts (say 200 or more). The most fundamental weakness is consistency. The majority of students make mistakes and the larger the number of scripts, the wider the variety of mistakes. This creates a headache for the assessor in terms of fairness and specifically with regard to the award of partial marks. The student may have answered the question incorrectly so the issue remaining is, *have they shown some understanding or an appropriate approach which merits partial marks?* Then of course, how many partial marks do they merit and how does this compare to the numerous other students for whom partial marks have been awarded? If it is 2 days since you marked a script with an equivalent error, will you remember and give the same mark again? The answer is probably not if several hundred other scripts have been considered since then. Also, different markers apply discretion in different ways.

This issue is compounded by student scripts being untidy, unclear and of poor legibility and so the marker is often guessing what the student has tried to do. Indeed some students have multiple attempts and do not clarify which answer they want to commit too! To what extent can partial marks be awarded based on the marker's interpretation of student intent and again, will this vary for two students having similar understanding and approach but a different presentation? An additional compounding factor is marker fatigue. Humans are unable, in general, to concentrate for long periods but typically the scripts needed to be marked within a very tight time frame, which means several days of *just marking*. It is inevitable that concentration will waver at different points and thus consistency will be lost.

Hence, the conclusion is that paper based assessment is not objective in general but rather is subjective being dependent on a combination of the marking scheme, marker concentration and fatigue, student presentation, staff understanding of what the student is trying to do, and more.

2.3 Students gaining credit for correct working

The classic argument for end of year examinations is that staff can observe student *working* and thus award partial marks for understanding even when the computations are

incorrect. However, it would be an interesting experiment for staff to look back at their marking to discern the extent to which this actually occurs. In the author's view, it happens far less than students perceive, in fact to the extent that it falls within the level of noise and the arbitrariness of any mark scheme/assessment process. That is, it is not significant for most students!

A typical engineering problem is scaffolded.

- (1) Part (a) is intended to be elementary and you expect all students to get this completely correct (or fail the module). Any computations **should be** straightforward and should not be done incorrectly by competent students. Not many marks for working as the computations elementary; right or wrong only!
- (2) Part (b) builds on part (a) and is used to distinguish a bare pass from a good performance. Students who got part (a) wrong may not be able to do aspects of part (b), especially where there is a single case study with numbers/parameters running through. Some credit may be available for working/generic statements where computations are incorrect.
- (3) Parts (c,d,..) build on parts (a,b) and are used to distinguish excellent from good performance; only a small proportion of students make progress with these parts. Students who got parts (a,b) wrong would rarely be able to make any progress with the more challenging parts and indeed one can view correct answers to parts (a,b) as being the entry pass to fight for the highest marks. Numeric computations may be dependent and thus correct answers to parts (a,b) are essential for a successful attempt at the latter parts.

A reflection on the typical scaffolded question above indicates that the potential for gaining marks *for working* may not be substantial. Due to the interdependencies in typical questions, students would rarely be able to state much useful beyond rather generic statements for the later parts where they had incorrect computations for the early parts. Generic statements are awarded credit at the level of pass/fail and okay performance (parts (a,b)), but for higher marks students need to demonstrate problem solving and application of learning and thus such statements would score negligible credit in parts (c,d).

One possible mechanism for gaining *working* marks is from *error-carried-forward* by which we mean that a student incorrect computation in say part (a), is used in parts (b,c,d). If they did the computations correctly thereafter, should they merit some credit. However, there are two obvious obstacles to this in practice: (i) It is not possible in general for assessors to check 'incorrect computations', when this applies to large numbers of students. If staff cannot do it for all, then fairness dictates they cannot do it for any. (ii) Often the numbers are carefully selected so that the latter parts of a question give sensible solutions and interpretations. A student performing incorrect computations will end up with a nonsensical or unuseful solution for which interpretations do not work.

2.4 Summary

The conclusion is that traditionally paper based end of year assessments are neither as objective nor fair as the

community and students perceive; in fact there are many weaknesses and that is even before consideration of the factor that many students do not cope well in such a stressful environment. It would be fairer to say that all assessment methods have limitations and we do not need to beholden to one type just because of tradition. The role of the lecturer is to design an assessment profile which is as fair and accurate as possible for a realistic time frame (say 10min marking per student per module).

3. REPLACING END OF YEAR EXAMINATIONS WITH AUTOMATED MARKING BY COMPUTER

This section makes an argument for how an end of year paper exam can be fairly replaced by automated computer marking. It is taken for granted that no practical assessment is perfect and thus different assessments have different weaknesses; you must make a choice. The ideal alternative of extended viva voce examinations for each student on each module is simply not viable.

3.1 Designing end of year exams for large classes

A core requirement in any quality assurance process is consistency so that students are all treated equally and it is clear that such a requirement is difficult to achieve with hand marking. Consequently, where staff have very large classes, the mark schemes will become increasingly pedantic to ensure fairness and consistency, for example:

- Allocate marks (0 or 1 and no partial marks) for specific computations.
- Allocate marks for specific observations (again no partial marks).
- Allocate marks for a correct figure or graph (this may have some partial marks for detailed drawings if the mark scheme breaks down to specific aspects of the drawing).
- etc.

The reader will notice that the mark scheme is being reduced to a tick box; you either get the mark or you do not. Removing the requirement to interpret the student working allows the assessor to be consistent and precise, but at the same time, essentially removes the opportunity for student to gain *marks for working*. Or, to be more precise, the evidence of student working is captured through the computations and observations which now have a specific mark. If you get the computation wrong, you can still get a mark for a correct observation, which in essence replaces what would have been marks for working.

It is implicit in the above that questions follow the scaffolding structure given in section 2.3, hence students who do not get the pass/fail parts (a,b) correct are largely ineligible for the higher marks on that question as both their computations would be wrong and any interpretations, being based on flawed data, would also be wrong.

3.2 Computer based assessment

The reader will realise that the question design used in the previous subsection is ridiculous to assess by hand marking. Once the mark scheme has become pedantic, it makes no sense to use a human painstakingly going

through student scripts, identifying correct components and adding marks manually; too many mistakes will occur! Instead, collect the core calculations and observations into a spread sheet, or similar, and ask a computer to assign the marks. Hence, that is the proposal in this paper.

This has the advantage that students must commit to an answer and, being uploaded on a computer, all the work is legible and unambiguous. Marking will be entirely consistent and thus fair. So, what is the difference with the paper based exam equivalent? With paper based marking, staff occasionally give some students 1-2% for evidence of understanding where there were no marks awarded for the corresponding calculations and observations. It should be emphasised however, that such generosity is rarely applied consistently and thus fairly, and is an arbitrary or subjective decision outside of the predefined mark scheme. This practice persists in all likelihood because most staff recognise that marking is an imprecise science and in reality you can only give any confidence of a mark representing student competence to within about $\pm 10\%$. Hence, many staff are not too concerned about a few marks here or there in that the main requirement is to ensure the assessment is delivering crude gradations of pass/fail, good, very good, excellent and so forth.

3.3 Question design

To ensure a computer marked assessment fairly distinguishes between different student competence, it is important to identify clearly the different learning outcomes.

- (1) What evidence is needed to award a pass?
Several questions should cover foundational knowledge and skills using only elementary computations which hence you would expect most students to get perfectly correct. Errors here should demonstrate fundamental misunderstanding or carelessness.
- (2) What evidence is needed to award a good or excellent performance?
Students apply the results from the early questions to perform new computations/designs and undertake increasingly levels of interpretation.
- (3) How can we mitigate against a silly student typo early in a question so they can still achieve a good mark?
As far as possible, arrange the calculation/observation dependencies in parallel paths so that students can make correct progress on some part (b) aspects, even if some of part (a) is incorrect. One can also insert few (but not lots due to time restrictions) standalone questions where data and graphs are provided so students are not dependent on previous computations.
- (4) How can we capture correct student working, even when some computations may be incorrect?
Ask students to match their intentions, or observations to a number of pre-prepared statements. These questions can be inserted in part (a) for foundational knowledge, part (b) for building knowledge and parts (c,d) for the advanced design/application parts.

3.4 Illustration of question design

Consider a typical control question which involves the analysis and design of compensators for a system $G(s)$.

- (1) The foundational knowledge will be aspects such as a root-loci plot, a Bode plot and a Nyquist plot. Different aspects of these plots, and the plots themselves, form the basis of some parallel threads. Moreover, one can assess the correctness of the student sketch with a multi-answer question (e.g. see Appendix).
- (2) Part (b) questions build on the plots and ask for interpretation, for example gain/phase margins, stability, expected behaviour and so forth. Several of these interpretations depend on separate parts from part (a) and thus students do not need to get part (a) correct entirely in order to score well on part (b).
- (3) Part (c,d) components will use higher level interpretation and design components. These may require a combination of insight from the various plots and earlier analysis and require students to perform more precise computations such as finding a lag compensator to achieve certain specifications.

4. EVALUATION

There are two core aspects to the evaluation of the proposal to use automated computer marking in place of end of year paper examinations. The first is validity: does the assessment deliver fair marks which appropriately distinguish between students of different performance levels. The second is student expectations: do the students perceive the assessment to be fair?

4.1 Student performance

To date this form of assessment has been trialled on 3 separate occasions. The data on student performance indicates that the assessment is delivering mark profiles very similar to those achieved on the paper based assessments of earlier years. However it is particularly notable in Figure 1 that students towards the bottom end of the performance scale (failing students) are scoring lower as the automated system is less generous at giving notional marks for weak evidence of understanding, notwithstanding incorrect answers. The mark profiles in figures 2, 3 are good in that an exam average of around 40-50% is as expected for this more challenging component of the module.

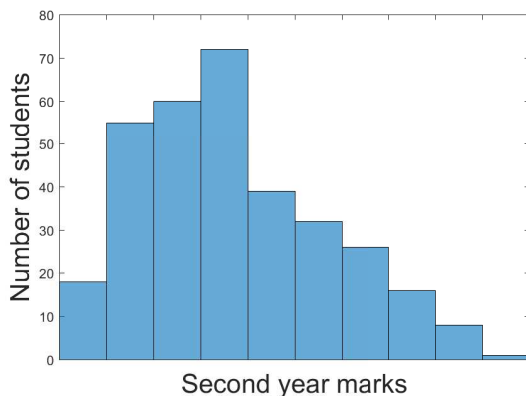


Fig. 1. Histogram of marks for examination 1 (year 2 students in 2018).

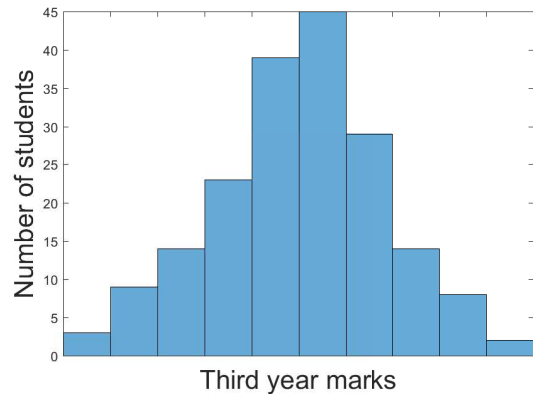


Fig. 2. Histogram of marks for examination 2 (year 3 students in 2018).

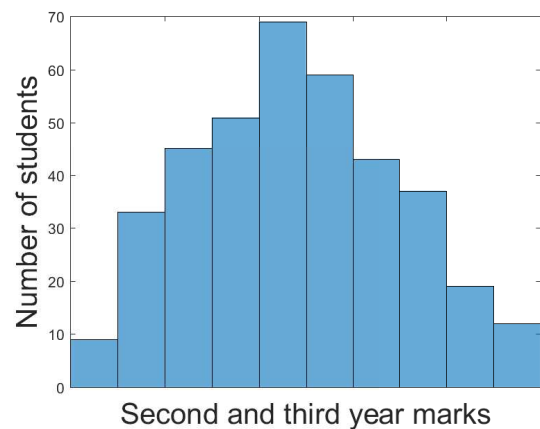


Fig. 3. Histogram of marks for examination 2 (year 2 and 3 students combined module in 2019).

4.2 Moderation of marks

It is essential to collect the actual student working, even though they submit their answers via a computer. Inspection of a sample of scripts is invaluable for discerning where questions were more ambiguous than expected and thus the mark scheme may need moderation, or the tolerances allowed for numerical answers may need to be modified. Fortunately, as the work is computer marked, any such changes to the mark scheme are remarked instantaneously and this constitutes a major practical advantage.

It is also important to assess the extent to which students have achieved a mark in the expected range so to compare hand marking to the computer system, and thus to validate that it has been fair (Rossiter, 2018). The author's experience is that the difference in marks between the two marking systems is typically small (less than 3%) and thus inconsequential given marking schemes are to some extent arbitrary anyway and we are looking mainly to distinguish students with clearly different performances.

4.3 Student expectations

Ironically, this has been the biggest challenge as students can be surprisingly conservative and comfortable in the assessment regimes that have experienced in the past. A

significant minority of students have expressed concern that they will be excessively penalised for small mistakes and not get a reward for good understanding when a single calculation has been incorrect. As detailed in this paper, the student perception is false, but it can be difficult to convince students even when they are provided with factual evidence. I suspect this issue is linked to culture and, as with any change, the more students are exposed to it, the more they will accept this as normal. In the interim, it is essential for staff to communicate effectively and clearly with students about the assessment.

5. CONCLUSION

A core point of this paper is to challenge the perspective that some how end of year written exams are the *gold standard* of objective assessment of a students' ability/learning. From the author's perspective they are neither as objective nor ideal as often perceived and he has been very pleased with the results of the proposed alternative. Although an automated assessment takes longer to write, his belief is that the marking delivers the mark profiles expected by the University and moreover, he believes the marking is fairer and more objective than hand marking of hundreds of often rather messy scripts, as well as being more efficient. It forces the examiner to think very carefully about question structure to properly distinguish different levels of performance and also forces students to commit to the answer they wish to be marked, and enter it legibly! Nevertheless, the main obstacle he has found is student perception, that somehow they will not achieve the mark they deserve, and this needs careful management.

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APPENDIX - EXAMPLE COMBINED PART (A,B) QUESTION ON ROOT-LOCI

This question combines parts (a,b) based on the production of a sketch (part a) and on the interpretation of that sketch (part b). [Some of question omitted to space space.]

Sketch the root-loci for $G(s)$ and select whichever of the following statements apply? Do not guess as incorrect answers will carry negative marks, so only select those you are sure are correct.

- The asymptote directions are $-180^\circ, 60^\circ$ and -60° .
- The asymptote directions are $-180^\circ, +180^\circ, +90^\circ$ and -90° .
- The real axis between -2 and -1 is on the loci.
- The real axis between infinity and -4 is on the loci.
- The root-loci has 3 asymptotes.
- The root-loci has 2 asymptotes.
- The system is closed-loop stable with low gain.
- The system is closed-loop stable with high gain.
- The system is closed-loop unstable with low values of gain but closed-loop stable with high gain.
- For high values of gain, the closed-loop system has 1 unstable closed-loop pole.
- For high values of gain, the closed-loop system has 2 unstable closed-loop poles.
- The closed-loop system is expected to have smooth behaviour with low values of gain but will have non-oscillatory and divergent behaviour for high gain.