FAST AND EFFECTIVE REMEDIES FOR THE DELIVERY OF WEB-BASED FORMATIVE ASSESSMENT MATERIALS

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Abstract *¾ Academics at higher education institutions are turning increasingly to web-based technologies to supplement and enhance their existing face-to-face teaching and develop richer learning environments for distance learners. An important part of this online teaching is the delivery of effective formative assessment allowing the student to test their knowledge and manage their learning efficiently. Staff engaged in this activity are faced with two challenges: the development of pedagogically appropriate assessment material and the rapid production of reliable web-based platforms.*

GLOW (Graduate Learning on the Web) is an HEFCE FDTL3-funded consortium project that is developing and testing tools and processes to assist academics to deliver web-based learning to postgraduate science and engineering students. A critical first step in this process is the creation of formative assessment materials. The project is developing a protocol based on the creation of self-contained learning objects containing self-assessment materials. Based on a single learning outcome, Bloom's taxonomy may be used to systematically generate assessment materials in a rapid and efficient way. Tests are produced that present the student with questions that enable them to assess the level of their learning and understanding; from low-level questions testing knowledge and comprehension to higher-level analysis and evaluation questions. The results of testing and demonstration of this approach indicate that it is viable and works well. To enable academics who are not web-specialists to develop assessment web pages rapidly, a freeware tool has been produced that allows the publication of self-assessment questions and accompanying feedback online. The emphasis in this system is on simplicity of use for the academic and embedding pedagogically proven structures within the proposed methodology.

Index Terms ¾ Formative assessment, postgraduate science and engineering, web-based assessment tool.

THE IMPORTANCE OF WEB-BASED ASSESSMENT

It is uncontroversial to assert that encouraging students to regularly test their knowledge will improve learning. Assessment and appropriate feedback are acknowledged as a key component of any educational system and in universities there has been a growing interest in the use of web-based assessment methods in recent years. A common use of web-based assessment is to create a series of question sets that test knowledge and understanding of particular topics, theories and concepts. Detailed feedback can be added to provide students with an instant assessment of their progress. Links to web-based resources, journal articles and pointers to text-based resources can be used to reinforce feedback. Thus assessment drives and reinforces student learning and feedback motivates them to remedy their areas of weakness. Extensive pre-web research showed that continuous formative assessment resulted in students gaining higher grades than peers who undertook no formative assessment [1]-[3]. As Biggs [4] comments 'Formative assessment is inseparable from teaching. Indeed the effectiveness of different teaching methods is directly related to their ability to provide formative feedback' (p. 142).

One type of formative assessment is self-assessment and Falkchikov and Boud [5] made the significant observation that *self-assessment* could be as reliable as other forms of assessment, particularly in science subjects. Much of the following discussion will focus therefore on formative self-assessment, although many of the comments could equally apply to summative and formal assessment approaches.

In addition to the general advantages described above, web-based assessment, particularly self-assessment, offers the potential to provide solutions to some of the challenges associated with assessing increasing numbers while maintaining quality of feedback. It also offers opportunities to assess material previously difficult to assess and the ability to create unique and authentic assessments in some circumstances. However, web-based assessment still remains a minority activity in most universities. What is preventing its more widespread adoption?

GLOW – ADDRESSING THE PROBLEMS OF WEB-BASED ASSESSMENT

Despite the acknowledged educational benefits, the design, development and delivery of web-based assessment are often seen as problematical. Many university teachers are

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unconvinced that compiling web-based self-assessment questions represents an effective use their time and energy. These misgivings seem to arise from four main issues:

- Assessment and feedback remains an afterthought in learning and teaching processes.
- There is concern over the investment of time necessary to learn to use software packages.
- Many lecturers lack the confidence to produce educationally sound web-based assessment questions.
- There is a preconception that web-based assessment can only assess lower order skills.

GLOW, a consortium-based project funded by the UK Fund for the Development of Teaching and Learning, is developing and testing tools and processes to assist academics without extensive web development skills or support to deliver high quality web-based learning to postgraduate science and engineering students. The efficient delivery of assessment, particularly self-assessment, is seen as a mission-critical component of best practice in web-based teaching. A major outcome of the project is to address the four issues described above through a variety of approaches.

- Firstly, GLOW adopts the position that to be effective assessment strategies and methods must be planned during the design of the learning materials but that academics require tools, templates and guides to help them through that process. The project takes an openly incremental and 'engineered' approach to developing and adopting web-based learning. It is believed that academic developers in science and engineering will identify with this type of methodology but even more importantly a structured approach will support the attainment of high quality teaching and learning outcomes.
- Secondly, the project has developed a freely available, easy-to-use assessment authoring package capable of handling a wide range of media (text, images, equations, photographs etc) that can be 'imported' into the questions.
- Thirdly, GLOW has analysed the processes involved in producing web-based self-assessment questions with the aim of significantly accelerating this process.
- Lastly, the project has developed both detailed guidance and examples of good practice to help academics go beyond multiple-choice tests that focus purely on assessing recall and design effective, sophisticated 'high-level' objective tests to give students the opportunity to demonstrate wide skills and understanding.

The GLOW assessment tool and the development processes will be described below.

THE GLOW ASSESSMENT PACKAGE

GLOW has developed, tested and released a free Linux-based software package that enables anyone to use a web-based self-assessment system installed on a server. The software allows university teachers to create tests for web-based self-assessment over the web. It is not intended as a replacement for the high-functionality systems found in commercial systems such as Question Mark Perception or as part of virtual learning environments such as Blackboard or WebCT. The software was designed with the specific aim that once installed, it would take less than a half-day's work for an academic with no knowledge of HTML or web development to set up her or his first web-based self-assessment pages. The development process is akin to filling out a simple web form.

Unlike more sophisticated packages, GLOW has not included server-based student tracking or monitoring of any type in this system. The reasons are both technical and pedagogic. The project wanted to create a low-maintenance system that could run on the type of server found in many science and engineering departments. Secondly the project emphasises autonomous self-assessment rather than formal assessment methods, so it was felt additional server functionality was unnecessary. The package does, however, include features to improve its accessibility for visually impaired users. Through the development of several hundred questions, the package has been tested by both beginner and expert academic users in the consortium institutions and has been enthusiastically received. The tool was also used to develop the self-assessment authoring protocol described in the next section, but the methodology may be applied generically, ie. it is independent of any software package or virtual learning environment.

OVERVIEW OF THE GLOW SELF-ASSESSMENT PROTOCOL

Based on Bloom's Taxonomy [6], the GLOW protocol enables the development of questions for learning outcomes associated with knowledge recall, comprehension and application to be produced very rapidly. Higher-level outcomes take more time, in that the directed feedback associated with question setting necessarily becomes more discursive and subtle. However, standard approaches to learning outcomes associated with analysis, synthesis and evaluation have also been developed.

The self-assessment protocol is part of a series of interconnecting tools, templates and guides designed to facilitate the development of web-based 'learning objects'. GLOW advocates a three-stage sequence to develop web-based learning objects, of which self-assessment is only a part.

Stage 1. Formal definition of the learning outcomes.
Stage 2. Systematic generation of questions based on the application of learning theory.
Stage 3. Development of web-based learning objects supported by the self-assessment materials produced in Stage 2

For many, concentrating on the assessment first may seem counterintuitive. However, starting with assessment means a fast payback in terms of lecturer time and energy. The lecturer produces useful, even vital, supporting materials and student-centred formative assessment early on in the development of web-based learning. Perhaps more importantly is the view that if a learning outcome is difficult to support with self-assessment and formative feedback on the web, then perhaps the learning outcome needs to be reviewed.

BUILDING A PROTOCOL

Anyone who has written questions for objective testing on the web will testify to the considerable amount of time it takes. A vital goal of GLOW is to significantly accelerate this aspect of web-based teaching. The project team has studied the processes involved in producing web-based self-assessment questions. Several hundred questions were developed in a range of science and engineering topics and an operational sequence emerged by trial and error as the most efficient. This engineered and incremental approach has enabled a scalable methodology to be developed that allows self-assessment questions to be developed incrementally, in spare half-hours, without the need for a significant initial investment of effort. Although it generally takes about four hours for an academic without experience to produce pedagogically sound self-assessment web pages, the production times reduce significantly as the user becomes increasingly familiar with the art and technology of producing self-assessment materials on the web. The following sections describe the approach that has been developed.

LEARNING OUTCOMES

The starting point for the development of any course resource or activity is to refer to the learning outcomes. This is the foundation step as it provides focus and context to the web-based self-assessment and eventually other web-based learning may be developed. The learning outcomes should define what a student will be able to accomplish after completion of a module or course and define coherent units of learning that can be further subdivided or modularised for classroom or for other delivery modes. Well-written learning outcomes state the type and depth of knowledge, skills, and attitudes that the students will gain and provide an objective benchmark for formative, summative, and prior learning assessment. The learning outcomes have a valuable secondary role to communicate expectations to the learners themselves, colleagues and external parties such as prospective employers.

IDENTIFYING QUESTION TYPE AND SEQUENCE

Many of us are familiar with the principle of developing skills and knowledge through a series of exercises of ever-increasing difficulty. This approach may be incorporated into web-based self-assessment. Analysis of the subject being taught and the learning outcome under consideration combined with the application of learning theory readily identifies the type and sequence of the questions that can be asked, or exercises that may be used.

There is no single learning theory that is best suited to all subjects and learning outcomes, as different disciplines and teaching strategies employ markedly different approaches. However, this project is concerned essentially with the teaching of science and engineering. In these subjects knowledge and expertise are organised in a structured and hierarchical way. Such an analysis would indicate that a structured objectivist approach such as that of Bloom and Krathwohl [6], who identified six levels of cognitive learning. Knowledge, the simple recall or recognition of facts, was regarded as the lowest level, followed by the increasingly more complex and abstract mental levels of comprehension, application, analysis and synthesis to Bloom's highest order which he as classified as evaluation. The GLOW project is concerned with learning outcomes that are appropriate for postgraduate training at masters level or above, i.e. "advanced study requiring a critical awareness of current academic problems, and the ability to advance new hypotheses" [7]. Thus the likely aim is the synthesis and evaluation levels in Bloom's learning hierarchy.

THE LIMITATIONS OF SELF-ASSESSMENT TECHNOLOGY

At present, most automatic marking techniques can handle questions that require a student to give an answer chosen from a list; or provide a small amount of unambiguous text. Essay-type submissions or answers that include diagrams or other multi-media type material are difficult for automatic marking systems to handle. In other words, in most cases we have to resort to some form of multiple-choice questions, or multiple response questions, or a short phrase entry. Clearly, it is straightforward to test basic factual knowledge using multiple choice and simple text entry formats.

A SYSTEMATIC, HIERARCHY-BASED APPROACH TO CREATING QUESTION SETS

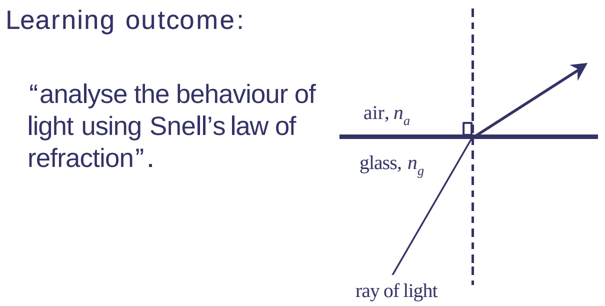
Given how the technology restricts the nature of the question, is it still possible to adequately assess a particular learning outcome, at all levels of learning? In general, the answer is yes, even for assessment of higher order skills such as synthesis and evaluation. GLOW suggests seven stages

1. Start with your learning outcome (see above);
2. decide what knowledge is essential to attaining the outcome and set questions to test that knowledge;
3. use questions to establish whether or not your student understands the concepts, definitions and terminology they need to know;
4. present simple applications to enable the student to gain familiarity and confidence in using their knowledge;
5. develop problems for your student to analyse using their knowledge, if possible bring in the additional application of supporting ideas and theories;
6. increase the complexity of the problems so that your student is encouraged to advance and test their own hypotheses in order to arrive at the solution; and,
7. present your student with questions that require them assimilate the “big picture”. Seek to guide them in the evaluation of their understanding of their own work.

Explaining how this may be achieved is best done by example.

Step 1: Start with your learning outcome

As an example we will use the following taken from a physics course.



Step 2: Decide what knowledge is essential to attaining the outcome and set questions to test that knowledge

Start off by getting your student to evaluate and assess their knowledge. This is easy to achieve with multiple choice, in this case one might ask:

$$n_1 \sin(q_1) = n_2 \sin(q_2)$$

In the above equation, n_1 and n_2 are:

A. The speed of light in the two different media.
B. The refractive indices in the two different media.
C. The densities of the two different media.
D. The optical path lengths in the two different media.

The student is being asked to identify the terms in the equations is being tested here. If they fail to answer this question correctly then they need to be guided to go over the course material and commit to memory the essential facts and terminology in which the course is based. In multiple-choice (or response) questions, the wrong answers (A, C & D) are often called ‘distracters’ and the basic rule is that they must be plausible but distinct from the correct answer. Many find that producing good distracters requires much more work than setting the initial question. One good way to find effective distracters is to ask a group of typical students to answer a question set without the list of possible answers. The incorrect responses that are received in this situation often make ideal distracters because they represent common misconceptions.

Step 3: Use questions to establish whether or not your student understands the concepts, definitions and terminology they need to know

The understanding of refraction can also be tested in a relative straightforward way, for example by the question:

During the process of refraction, a light beam

A. bends at the interface between two media with different refractive indices.
B. is totally retained within one medium.
C. interferes with itself.
D. bends as it encounters an edge or small gap.

Here, the student is tested to see if they understand what physical phenomenon Snell’s law describes. An advantage of computer-based self-assessment systems is that students can be given immediate feedback. This feedback can range from simple encouragement to advice on further study and to an explanation why an answer was wrong. For instance, to the above question you might give the following feedback depending on the student’s response:

A. Correct answer. Well done!
B. No. Light is only totally retained during total internal reflection.
C. No. Interference requires multiple beam paths. See Section 5 of your lecture notes.
D. Wrong. Light is bent at edges or small gaps by diffraction. See page 100 of your course textbook.

Step 4: Present simple applications to enable the student to gain familiarity and confidence in using their knowledge

The next step is straightforward and testing application of a scientific principle or law can usually be done numerically.

A beam of light in air (refractive index =1) forms an angle of 30° with the normal to a plane glass surface of refractive index = 1.5. What angle does the ray make to the normal in the glass?

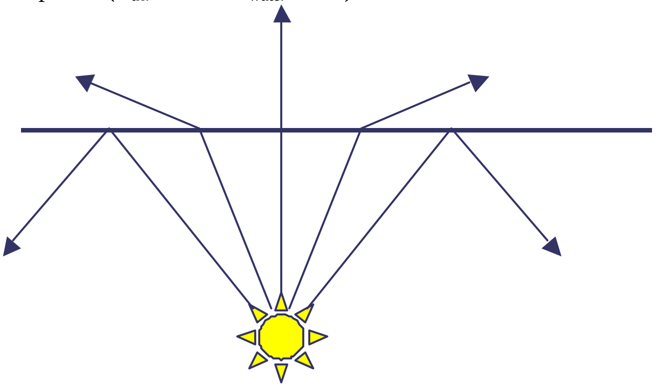
A. *30°*
B. *19°*
C. *35°*
D. *55°*

Here, the wrong answers are not just randomly picked but correspond to answers that would be calculated if Snell's law was applied incorrectly. The feedback at this stage should also contain a model answer. However, try to arrange it so that it isn't given automatically. Students might want to try and work it out for themselves first.

Step 5: Develop problems for your student to analyse using their knowledge, if possible bring in the additional application of supporting ideas and theories

With level 4 and beyond, higher level skills are tested and hence a little more thought is required to write good questions. Problems that require analysis and application are required.

A light source that emits in all directions is placed at the bottom of a swimming pool at a depth of 2 metres. What is the diameter of the resulting circle of light on the surface of the pool? (n_{air}=1 and n_{water}=1.3)



A. *2.4 m*
B. *3.4 m*
C. *4.8 m*
D. *1.7 m*

In this example, the student is not simply given numbers to feed into the equation but must instead analyse a physical situation using Snell's law. They will need to use simple geometric relationships in conjunction with Snell's law. They will also need access to clear worked examples.

The distinction between learning levels can be blurred, however, so what in the above question might be considered a test of analysis for one student and may be closer to simple application for one who is more able. What constitutes a question of a particular level is a judgement that a lecturer makes based on their knowledge of the class.

Step 6: Increase the complexity of the problems so that your student is encouraged to advance and test their own hypotheses in order to arrive at the solution

The extra complication afforded by multi-response questions (ie. none, some or all answers may be correct) can be useful in testing higher order skills, as well as reducing the likelihood of correct guessing.

If a light ray is to be guided down a stream of water flowing from a cylindrical pipe which of the following conditions are helpful?

A. *Low water pressure.*
B. *Non-turbulent water flow.*
C. *Gentle curvature of the stream path.*
D. *Fast water flow.*

To correctly answer this question, the student has to imagine how the objective could be achieved, in this case the guiding of light by a stream of water, and what would be important for its success. (The correct answers would be B and C, in this case.)

Step 7: Present your student with questions that require them assimilate the 'big picture'. Seek to guide them in evaluating their understanding of their own work.

This level of question is meant to test a student's ability to evaluate, appraise or judge. Again, though, whether a particular question tests these skills depends not only on how it is written but also on the level of the students for which it has been written and how the course it supports has been delivered. For instance, for our Snell's law example, consider the following question:

Which of the following models of optics best describes Snell's law?
A. *Wave optics*
B. *Photon streams*
C. *Ray optics*
D. *Maxwell's equations.*

For students who have not been exposed to a discussion on the different formalisms used in optics and how they are related, this question prompts reflection on the nature of the general model of light that is used to describe refraction: a step back to look at the big picture. In contrast, for students who are very well versed in optics this represents a simpler level of question that could be classed as factual classification.

Evaluation skills can also be fostered using a question that asks your student to reflect on their work, and then present answers that guide their evaluation process.

You have used a submerged light source to estimate the depth of a body of water. The depth of the water at 12:00 hrs on the day of your experiment was 25.3 cm ± 0.05 cm. Was your estimate significantly different from this? Which of the following environmental factors would you consider when evaluating your data?

A. *Temperature of the air.*
B. *Temperature of the water.*
C. *Atmospheric pressure.*
D. *Intensity of the light source.*
E. *Source of the water.*
F. *Volume of water used.*
G. *Acoustic noise and mechanical vibration within the laboratory.*

In setting this question you are inviting your student to reflect on the conditions under which an experiment was undertaken and to identify the key issues that they need to consider in their write up.

The feedback they receive at this stage can pose further questions to encourage your student to research more deeply into perhaps more subtle attributes of their work. for example

A. *Temperature is important in that the refractive index of air changes with temperature. Why is this and what further tests might be undertaken to characterise the relationship between refractive index and temperature? Think also about how the air temperature could affect the depth of the water at the time of measurement.*
B. *The role of the water temperature is more complex than that of air. What is the effect of temperature on the refractive index of water? But consider also the heating or cooling effect of water on the air at the boundary between the phases and on the stability of the experimental set up. Does water temperature play a role in the water depth at any point in time?*
C. *Pressure and temperature are of course related in the gas phase. So in looking at experiments to characterise temperature relationships account needs to be taken of pressure.*
D. *What was the power dissipated by the light source into the body of water? What effect on the water will the source have, and will it be significant?*
E. *There are two sources of water in the laboratory, which one was used? Is there a difference in the refractive index between tap water and water drawn from the water purifier? If so, what is it and why?*
F. *The volume of the water used in the experiment is an important factor. There were three possible experimental set ups you could have used. The depth of water was the same in all of them, but their volumes were different. Think about the specific heat capacity of your system when considering this issue.*
G. *Did you observe ripples on the surface of the water? How would such an artefact affect your results? How might you address this issue in your experimental design?*

CONCLUSION

Based on a single learning outcome and using Bloom's taxonomy as a guide, the GLOW seven-stage protocol offers a structured and incremental framework for developing question sets which test several levels of cognitive learning. It is recognised, of course, that in practice it can be a daunting task to find the best or most appropriate questions to use. Distracters are often difficult to create and it isn't always possible to collate and analyse student responses to questions in the time available. However, the project is confident that over several academic cycles using the GLOW methods your web-based self-assessment resources will be substantial, a valuable asset to you and your students. A detailed manual for authors explaining the protocol is currently under development to be published on the GLOW website [8].

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