



Educator's Corner

Open-Book Examinations for Assessing Higher Cognitive Abilities

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An open-book exam permits the examinees to consult some selected reference sources or materials (such as their own notes, the instructor's handouts, or books) in the course of answering the exam questions. Many variations of such an exam are possible. It need not be a written one, even an oral exam can be conducted in an open-book manner. An exam need not be open book in its entirety, it can include a part that is closed book. The reference material may be known and accessible to the students (such as handouts distributed earlier), or it may be newly supplied material not previously seen by the examinees. Finally, the permissible material may be identical for all students (such a textbook or datasheet), or it may be selected or prepared by the examinees themselves (such as notes, portfolio of classroom work, formula sheet, or choice of books).

The primary distinction between the traditional closed-book exam and one that is open book is that a closed-book exam places a premium on accu-

rate and extensive recall, and unless carefully designed, its assessment of students' knowledge is likely to be dominated by that ability. The ability to recall information is indeed an important cognitive goal—it is the lowest-level ability in Bloom's hierarchy of educational objectives in the cognitive domain [1] and is therefore an essential antecedent to the higher-level abilities. But while it is necessary, it is not sufficient for attaining such skills as problem solving and creativity. Hence the need for focusing on higher-level abilities in instruction and assessing them without an excessive influence of recall.

In an open-book exam, the influence of recall, while still significant, can be diminished by careful design. The availability of reference materials provides another degree of freedom in constructing the exam questions, which can be utilized to direct the exam at different educational attainments, e.g., understanding instead of recall. Since exams serve to motivate the students, with appropriately placed emphasis in the exams, an instructor can promote teaching and learning at higher levels of the taxonomy of cognitive abilities.

The suitability of the open-book exam format can depend on a number

of other considerations as well, some of which are summarized in Table 1. There is little reported research on the subject, much of it surveyed in [2] and [3], and the potential advantages and weaknesses listed in Table 1 are based more on experience and belief rather than on the results of rigorous educational research and longitudinal studies.

Problems for Open-Book Exams

If the expected benefits of open-book exams are to accrue, the instructors preparing the exam questions must first learn to take advantage of the format.

Selection of exam questions usually rests on multiple considerations, such as the need for a broad sampling of the subject matter to avoid an uneven emphasis in coverage; this leads to a preference for a larger number of problems, in turn decreasing the amount of time available for each. At the same time, the choice of problems is constrained both in respect of their depth (which influences the level of difficulty experienced by the intended examinees), and their length (so as to ensure that the amount of required work is appropriate for the available time). These constraints force the exam problems to be familiar, short, single-step, simple and idealized problems, or snippets of somewhat more realistic problems, to keep the cognitive workload at a reasonable level. In a

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TABLE 1. Strengths and limitations of the open-book exam format (as compared with a closed book exam).

Potential Strengths	Possible Limitations or Risks
Open-book exams emphasize the ability to locate, discriminate or select, and apply knowledge, and deemphasize the importance of memorization.	Every examinee is expected to have access to a copy of the same reference works, books, etc.
Open-book exams could lower the anxiety level of students who find reassurance in the available books and other reference materials.	There is less motivation for the students to organize all of the materials in their mind, or on a formula sheet, prior to the exam, and a tendency to rely on the reference materials.
The scope of an open-book exam can be broader, because the examinees are expected to look up or call upon any and all of the information in the reference sources rather than just the highlights that they could have been reasonably expected to recall. This provides an additional incentive for a thorough study of the materials that are to be available.	Some examinees may underestimate the time needed to consult the open book during the exam.
Open-book exams could permit more realistic exam questions rather than the highly idealized ones typical of closed-book exams, thereby more accurately representing the reality and pattern of professional work wherein the information resources are available, and intelligent use thereof is expected.	Some students may treat the exam time as the time to learn from the book for the first time, rather than study it thoroughly in advance.
Homework assignments and other learning experiences already prepare the students to solve problems with the assistance of external resources, so the open-book exams are more natural than the closed-book ones.	The burden of proctoring is increased if it is necessary to ensure that the students have only the permissible materials.
Spared from the burden of recall, the students are likely to focus on higher cognitive abilities and hopefully, even reflect on the learning strategies needed in an open-book environment, <i>vis a vis</i> their own style, thereby gaining some metacognitive awareness.	The students' workload is also increased if they are responsible for the preparation and selection of reference material to be used during the exam.

closed-book exam, where the cognitive workload is already higher due to the need to recall, it becomes difficult to construct problems that address a variety of learning objectives at higher levels of Bloom's taxonomy of educational objectives [1] and that are short and simple at the same time.

In an open-book exam, the constraints on the depth and length of problems can be less severe, because the reference material serves as a repository of information, thereby relaxing the cognitive demands on the examinee. This lowering of demand can be exploited in two ways: 1) by increasing the number of problems to allow a wider sampling of subject matter and educational objectives or 2) by constructing higher-level problems that are more demanding of ability and time. Thus, an open-book exam might permit a somewhat larger number or a larger variety of problems. The possibility of including problems aimed at higher-level abilities is a major benefit of the open-book exams, and some ways of constructing them are suggested in the following.

One obvious way in which open-book exam problems can be different is their dependence on the use of detailed tabular, graphical, or numerical data, which can neither be easily supplied as part of the problem statement, nor expected to be recalled by the examinee, in a closed-book exam. Some examples of such information are lists of integrals, series expansions, Fourier or Laplace transforms, mathematical identities, conversion factors, and tables of special functions. In a closed-book exam problem, this option is not conveniently available, and if exercised it alters the underlying task, because supplying a required formula, or a specific part of some extensive data, becomes a clue to the solution of the problem. Thus, including a particular transform pair in the problem statement serves as a prompt or cue that directs the examinees effort towards arriving at a need for that result, instead of focusing on problem solution.

An even larger class of problems, that becomes suitable for exam use in an open-book format, is that of multi-

step problems. The level of difficulty of a problem appears to increase almost exponentially with the number of steps involved in its solution, making multistep problems almost prohibitive in closed-book exams. This explains the predominance of single-step problems, or problem segments obtained by deleting all but one or two steps, in closed-book exams. A multistep problem become amenable to solution by examinees when the effort involved in carrying out one or more steps is drastically decreased by the use of ready information available in the permissible reference works. Such information may be contained in a compilation of canonical cases, formularies, empirical approximations, a numerical solution in normalized form, tabulated results, or a solved exercise. An example is the set of expressions needed to carry out a transformation from an impedance matrix $[Z]$ to a scattering matrix $[S]$ description of a linear two-port network; its availability can significantly decrease the time required for solving

TABLE 2. Strategies and caution for beginners.

Advice to Instructors	Caution to Students
Decide whether all or only a part of the exam is open book (consider if it is needed to encourage the students to study the book in advance, or if the inclusion of recall in the skill set under assessment is deemed desirable), and inform the students early (preferably at the beginning of the semester) so as to allow them to direct their study appropriately.	The open-book exam problems will often be harder than those in a closed-book exam to compensate for the fact that recall is not needed and a larger range of information can be placed at the students' disposal through the open book.
Establish and announce what materials are permissible and whether they are selected by the student or the instructor.	There is no longer any reward (or need for partial credit) for merely knowing the right formula or procedure or for reproducing information if it is available in and can be copied from the permissible reference material. There is a larger premium on knowing applicability of constraints in, or limitations to, the use of that information, as well as assumptions or approximations implicit in the use of that information. Greater attention is needed on accurate execution of the steps starting from the information available in the book, since only the ability to go beyond the information is rewarded.
Select exam problems that take advantage of the open-book format of the exam, e.g., by designing problems that require the integration of information from multiple parts of the book.	If the examinees are responsible for selecting and preparing their own resource materials, accuracy of the prepared material is also their responsibility. The material can be customized for speedy retrieval of significant information, by highlighting, underlining, tabs, color coding, etc. Having excessive materials can be a disadvantage.
Tell students in advance what will and what will not be rewarded by partial credit; for example, selecting the appropriate formula to be used in solving the problem may be a worthy accomplishment (if it requires choice, or verifying the conditions of applicability), while reproducing the formula from the book is not.	

some problems. Recreating such a transformation can take time, is not done in practical situations due to its common availability and may not be the skill an instructor wishes to test the examinees for. Use of partial solutions typically contained in available references is also an excellent training in developing the skill of chunking that experts are known to deploy [4].

Perhaps the most remarkable departure from closed-book exams occurs in an open-book exam problem that is more encompassing in scope and integrative. Such problems require the examinee to draw upon and integrate information from multiple sources (e.g., different sections or chapters of a book), or of multiple types (e.g., device data, specifications, and standards) that is found in different sources (such as books, data sheet, and application notes) to solve the problem. Despite the broader scope of an integrative problem, the examinee's workload can still remain reasonable through clever design and selection of the problem. One example is to construct a problem that is composed of several subproblems, all (or many) of which are already included as solved exercises or canon-

ical examples in the permitted reference work, although scattered among different sections or chapters where they are used to illustrate different principles and procedures. Such a problem will likely be unsuitable for a closed-book exam because it would require the solution of individual subproblems as well, which could overwhelm the cognitive resources of the examinee. In an open-book exam, the examinee's primary task involves only the planning and integration of the solutions of subproblems that are already available in the reference material. The examinee is thus called upon to perform tasks requiring higher level cognitive abilities.

At the same time, some questions that are suitable in a closed-book exam are not appropriate for the open-book exam format, e.g., because they ask for a direct reproduction of information supplied by the reference materials. Examples are questions that ask for definitions, descriptions, block diagrams, theorem statements, solved exercises, lists of properties, characteristics, or advantages, etc. already contained in the reference work. Many of these questions can be rephrased for use in an open-book exam. Thus, a problem that asks for a definition

of a parameter (e.g., "what is image frequency") can be replaced by one that asks for applying that definition to determine the value of that parameter ("find it from the given spectra of mixer input signals") or discriminating it from other similar parameters ("distinguish it from the intermediate frequency").

Logistics for Successful Transition

A transition from closed-book to open-book exams may require an adaptation period, both for the examiners and the examinees. Table 2 shows some recommendations to make the transition smoother, based mostly on reported experience.

References

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