Do computer simulations of laboratory practicals meet learning needs?

Ian E. Hughes

There is a variety of pressures on pharmacology teachers to replace real laboratory practicals with simulations but do they help students achieve the required learning objectives? In this article, the marks obtained by students in a variety of assessments using ‘wet’ or simulated practicals are analysed. Poorer performance in practical write-ups by students doing ‘wet’ practicals compared with those doing simulations can be explained by the quality of the data that the students obtain. In examinations, students perform equally well except with questions that are related to the experimental details of ‘wet’ practicals; students taught using such ‘wet’ practicals perform better in response to these questions.

Throughout the past decade there has been a variety of pressures on pharmacology teachers to replace real laboratory practicals with simulations but do they help students achieve the required learning objectives? In this article, the marks obtained by students in a variety of assessments using ‘wet’ or simulated practicals are analysed. Poorer performance in practical write-ups by students doing ‘wet’ practicals compared with those doing simulations can be explained by the quality of the data that the students obtain. In examinations, students perform equally well except with questions that are related to the experimental details of ‘wet’ practicals; students taught using such ‘wet’ practicals perform better in response to these questions.

Learning objectives of laboratory classes

The learning that takes place in laboratory classes does not just involve development of laboratory skills. Indeed, a considerable list of diverse items is learned or developed in the laboratory context (e.g., knowledge discovered by performing the experiment, experience of the scientific method and the application of theoretical knowledge in a practical context). In addition, skills that are learned include accurate pipetting, cannulation of blood vessels, handling of animals, time management, experimental design, task organization, report writing, communication and working in a team. Attitudes are developed in relation to being prepared to put in the effort required to get the experiment right, to set high, self-imposed standards, to be neat, careful and clean at the laboratory bench, and to be self-critical and open-minded. Aptitudes are also discovered and we all know of the very bright student who is clumsy to the point of being a disaster area.

Analysis of the teaching and learning objectives of 26 practical classes involving animals in universities in the UK showed that the median number of learning objectives explicitly associated with each practical class was six, and that generally only two of these involved practical skills. The range of teaching and learning objectives included: (1) illustration and exemplification of theoretical knowledge of drug effects; (2) acquisition of general laboratory skills and manual dexterity; (3) acquisition of specific subject-related laboratory skills (e.g., cannulation); (4) development of a robust and self-reliant attitude to practical work; (5) teaching factual knowledge; (6) teaching about integration of complex systems; (7) teaching of research methodology; (8) development of problem solving in a real environment; (9) development of independent working; (10) training in manual and technical skills; (11) attitudes to animals (justification for use, responsibility to minimize suffering and reduce wastage, care of experimental animals and preparations); (12) acquisition of animal-handling skills; (13) development of written and verbal communication skills; (14) development of data handling, collection and processing skills; (15) improvement of time management; (16) development of team-working skills; (17) development of organizational, planning and experimental design skills; and (18) acquisition of self-discipline.

It is possible that all these learning objectives might not be appropriate for all students taking a science course. Twenty years ago, BSc honours pharmacology courses might take 10–18 students and it was common for 90–100% of pharmacology graduates to enter employment or further training in areas that required direct use of the practical skills acquired from their course. Today, 80–100 students graduate from some pharmacology courses and <50% enter an occupation that directly requires the practical pharmacology skills taught on the course. Very few pharmacy or medical students will ever need pharmacological laboratory skills. For such students, particularly in the first year of the course, the laboratory classes are primarily concerned with illustrating and reinforcing theoretical concepts taught elsewhere. Although learning objectives involving laboratory skills might be appropriate for some students, they are not necessarily appropriate for all the students on a course. Students who learn from simulated experiments might lack laboratory skills that are difficult to acquire in a simulated environment.
Do alternatives meet the learning needs?

The crucial question is whether simulations enable the required learning objectives to be met. Where acquisition of laboratory skills or discovery of aptitudes is a prime learning objective, simulations that reduce students’ laboratory experience are not necessarily desirable, although the use of a simulation before a real practical might better prepare students for what they will encounter in the laboratory. Where these are not prime learning objectives simulations might reduce teaching costs13 and meet moral objections and other pressures, and the student’s attention can be directed towards the specific learning objectives without the distraction of the laboratory manipulations required in a real experiment. Simulations provide students with data and can be integrated with the learning of skills such as data handling and interpretation, communication and report writing, and experimental design. These are important skills, much in demand by employers, and are in addition to the understanding of the pharmacological principles provided in the simulated experimental situation.

Simulated experiment versus ‘wet’ practical

The academic performance of students doing ‘wet’ practicals (where students set up and manipulated their own tissue preparations, prepared their own solutions and calculated and prepared the doses and concentrations to be used as specified in the exercise schedule) or those who were taught using a computer-based simulation (where the student followed a schedule and entered the nature and concentration of drug required and the simulation provided a record from which the size of the response was measured) has been analysed. For each group, the marks obtained for the assessed (by academic staff) write-ups produced by first year students studying pharmacology have been used. In all cases, students followed a schedule that had a major experimental part that involved writing up and interpreting the experimental results and then a minor part consisting of some questions that tested understanding of the theoretical implications of the material dealt with in the exercise. Table 1 shows the marks awarded for the experimental part of the write-up in five separate studies in which students were divided into those doing ‘wet’ practicals and those doing the simulation. Students either chose to do the simulation (Study 2), were allocated to a simulation group (Studies 4 and 5) or used the simulation because they had been absent from the practical class (e.g. because of illness) (Studies 1 and 3), chose to do the simulation (Study 2) or were allocated to a simulation group (Studies 4 and 5).

<table>
<thead>
<tr>
<th>Study</th>
<th>Nature of scheduled exercise</th>
<th>Practical component</th>
<th>Theory component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wet</td>
<td>Simulated</td>
<td>Wet</td>
</tr>
<tr>
<td>1</td>
<td>Selectivity of antagonists$^a$</td>
<td>46 (n = 39)</td>
<td>60 (n = 16)</td>
</tr>
<tr>
<td>2</td>
<td>Reproducibility of concentration–response curves</td>
<td>59.0 ± 8.4 (n = 18)</td>
<td>76.5 ± 3.2 (n = 73)</td>
</tr>
<tr>
<td>3</td>
<td>Potency ratio of two agonists</td>
<td>55.6 ± 2.1 (n = 50)</td>
<td>70.3 ± 4.9 (n = 22)</td>
</tr>
<tr>
<td>4</td>
<td>Potency ratio of two agonists</td>
<td>58.1 ± 2.4 (n = 40)</td>
<td>75.8 ± 3.1 (n = 45)</td>
</tr>
<tr>
<td>5</td>
<td>Measurement of affinity constant$^c$</td>
<td>56.4 ± 4.6 (n = 42)</td>
<td>785 ± 3.8 (n = 46)</td>
</tr>
</tbody>
</table>

$^a$ Students within each of the five studies were divided into those doing ‘wet’ practicals and those doing the simulation. Students either used the simulation because they had been absent from the practical class (e.g., because of illness) (Studies 1 and 3), chose to do the simulation (Study 2) or were allocated to a simulation group (Studies 4 and 5).

$^b$ The percentage scored for each exercise is given (mean ± SEM) with the number of students shown in parentheses.

$^c$ Abbreviation: NR, not recorded.

$^d$ This experiment was assessed on an alpha to gamma scale but has been converted to a numeric value to calculate a mean. Because the resulting data are not continuously graded, standard errors have not been calculated.

$^e$ These data are drawn from two cohorts of students, the first of which did the ‘wet’ practical, which was then replaced for the following year by the simulated exercise. The n values are different because some students failed to hand in completed write-ups.

However, there are caveats that should be appreciated. In Study 2, although the students were part of the same cohort, the groups were not in fact of equal ability (assessed by their overall performance in the examinations). The group doing the ‘wet’ practical scored 63.4 ± 5.6% (mean ± SEM) whereas those doing the simulation scored 55.2 ± 4.8% (mean ± SEM) in the examinations in the previous semester (i.e., this was not a difference caused by their experience of the...
Box 1. Comprehension and learning measured three months after completing 'wet'-laboratory or simulated practical exercises

The four questions listed below were part of a 30-question paper set to two cohorts of first-year students studying pharmacology. The correct answers are indicated as true or false. Those answers considered to deal mainly with practical (P) or theoretical (T) matters are indicated, and the percentage (rounded to a whole number) of correct answers from the 46 students doing the simulated practical and the 42 students doing the 'wet' practical, respectively, is shown in parentheses after each completion.

Q1 The isolated guinea-pig ileum preparation
1. The pA₂ for acetylcholine is likely to be about 9.0 (false) T(43%, 67%)
2. in Tyrode's solution is exposed to a Ca²⁺ concentration of 1.1 µM (false) P(43%, 52%)
3. produces the best recordings with an isometric transducer (false) P(11%, 48%)
4. is usually set up with a load of 0.5 g (true) P(9%, 36%)
5. in Tyrode's solution is usually gassed with 95% oxygen/5% carbon dioxide (false) P(33%, 71%)

Q2 An isolated organ preparation containing muscarinic receptors is set up in a 20 ml organ bath
1. the pA₂ for acetylcholine is likely to be about 9.0 (false) T(43%, 67%)
2. a dose of 1 mmol would produce a bath concentration of 20 µM (false) P(11%, 48%)
3. 0.5 ml of a 1 x 10⁻⁴ M solution would give a bath concentration of 2.5 µM (true) P(17%, 64%)
4. a dose of 0.1 nmol of atropine would be likely to produce a significant effect on the size of the response to acetylcholine (true) P(39%, 81%)
5. the maximal response to carbachol and acetylcholine would be the same (true) T(33%, 52%)

Q3 In an isolated piece of guinea-pig ileum
1. carbachol would produce a contraction (true) T(93%, 100%)
2. atropine would produce a relaxation (false) T(78%, 76%)
3. acetylcholine is a full agonist (true) T(89%, 90%)
4. all muscarinic agonists would produce the same maximal response (false) T(87%, 86%)
5. of small size (<1 cm), a smaller concentration of acetylcholine would be needed than in a larger sized piece (>2 cm) (false) T(83%, 79%)

Q4 The Arunlakshana Schild plot
1. uses log₁₀(dose ratio – 1) for the y-axis (true) T(91%, 93%)
2. uses log₁₀ agonist concentration for the x-axis (false) T(94%, 98%)
3. would have a slope of 1 if antagonism was competitive (true) T(98%, 88%)
4. with a slope significantly greater or less than 1 indicates antagonism is non-competitive (false) T(72%, 83%)
5. will give a value for pA₂ at the intercept on both the x- and the y-axis (true) T(89%, 90%)

practical). This is not a statistically significant difference (P >0.3) but the mean values are not identical. However, if this were a real difference it would tend to suggest that the 'wet' practical group were the better students and should therefore have obtained a better mark; in fact, these students performed less well. In Studies 4 and 5, the result is complicated by the fact that the classes were marked in a slightly different manner, particularly with regard to the requirements to include the annotated record (trace) from the experiment. Even taking these problems into account, the difference between the performance of the two groups in each study is still both consistent and considerable, which suggests that students doing the simulation produced better write-ups than the students doing the 'wet' practicals.

Analysis of differences in performance
Analysis of the students' work showed that the most crucial difference was that some of the 'wet' practical students failed to obtain consistent or reliable data, whereas high-quality and consistent data were obtained by all students using the simulation. It is more difficult to write up and interpret data confounded by spurious, incomplete or inconsistent results than it is to produce a good write-up from consistent and complete data. The difference in marks does not therefore necessarily reflect only differential achievement of the learning objectives, it might also reflect the difficulty of the task resulting from the quality of the data available to the student.

The exercise schedule usually contained questions to test understanding of theoretical principles, and in this part the 'wet' practical and simulation groups performed equally well (Table 1). In no case was there a statistically significant or consistent difference and thus, with respect to learning and understanding the theoretical principles involved, the simulation is as effective as the 'wet' practical.

In Study 5 additional data were available from examinations at the end of the academic year (four months later); the two cohorts of students in the study were found to perform very differently in four multiple-choice questions related to the material involved in the experiment ['wet' practical students: 71.4± 4.6%; simulation students: 56.8± 5.3% (mean ± SEM, P<0.05, Student's t-test)]. Those doing the 'wet' practical performed better than those doing the simulation possibly because the 'wet' practical group benefited from having contact with academic staff during the practical, or because the 'wet' practical was longer in duration than the simulation (3–4 h compared with 40 min for the simulation). This might suggest that the simulation evoked shallow learning whereas the 'wet' practical evoked deeper learning.

Consideration of the content of the multiple-choice questions suggested that the difference in performance might be related to the type of information examined. Box 1 shows the actual questions set in the examination and the percentage of students in the 'wet' practical and simulation groups providing correct answers for each of the completions. Each completion has been classified as requiring primarily practical information (P; n =8) or primarily theoretical information (T; n =12).
The mean percentage of correct answers given by the simulation and the ‘wet’ practical groups to each of the practically orientated completions was calculated (23.4 and 53.3%, respectively) whereas the performance of the two groups in the theory-oriented completions was 79.2% and 83.5%, respectively. The data show a marked difference in the performance of the groups in the practically orientated completions (more than twofold) but little difference with respect to the theory-oriented completions. However, this type of analysis is not amenable to simple statistical treatment because the variability from several sources is compounded. To remove this effect, a ratio has been calculated for each completion of the percentage correct answers provided by the ‘wet’ practical group to that of the simulation group (Box 1). The mean ratio for the practically orientated completions was 2.84 ± 0.45 (mean ± SEM, n = 8) and was significantly different (P < 0.001; Student’s t-test) from that for the theory-oriented completions (1.11 ± 0.07 (mean ± SEM), n = 12), which was itself not significantly different from unity (P > 0.2).

It therefore appears that the performance of the two groups of students was not different with respect to their theoretical knowledge as examined here but that the ‘wet’ practical group was better able to recall the practical details of the experiment that they had performed. It is interesting to speculate whether this information had been forgotten by the simulation group (reflecting shallow learning) or was, in fact, never learned. Because we did not examine the knowledge of these students in this respect immediately after the theory exercise was completed, we do not have the data to resolve this point.

Concluding remarks

Computer-based simulations can provide a learning aid that is as effective as ‘wet’ laboratory practicals for developing knowledge and understanding that does not involve practical details of the experimental methods being used.

References


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