The effectiveness of separating theory and practicum as a conduit to learning physiology

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Submitted 3 December 2012; accepted in final form 18 January 2013

Many conventional science subjects use practicals to encourage students to think critically, a quality that requires much nurturing, encouragement, and careful assessment. However, evidence shows that students completing science courses involving practical classes do little if any better on assessments than students completing similar courses not involving practical classes. A common issue in many conventional courses involving practical classes do little if any better on assessments than students completing similar courses not involving practical classes. A common issue in many conventional courses is that subjects with embedded benchwork activities are designed with objectives focused more on developing manipulatory skills rather than on promoting methodical thinking and metacognitive learning. Educators have "produced foolproof 'experiments' where the right answer is certain to emerge for everyone in the class if the laboratory instructions are followed. Science is presented as a body of information which is verified and certain". This process, although demonstrating to students that applying formulae to solve problems is commonly effective, is akin to rote learning anatomic structures. Kirschner (6) proposes that practicals that are properly planned can show students that "alternative procedures, devising related experiments and choosing the means for recording and interpreting observations" can provide a more effective route to concept attainment and deep learning.

With this in mind, our objective was to develop a separate physiology practicum subject at the second-year university level. Before 2010, students from a wide variety of courses enrolled in a second-year level physiology subject as a 20-credit point subject (out of a total of 60 credit points taken by students each semester). In line with the shift within the university to ensure that all subjects had a value of 15 credit points (or multiples thereof) at all levels of a course, we were required to shift from a 20-credit point subject to a 15-credit point subject with an associated reduction in content. A decision was made to remove the embedded practicals from the subject and rebrand the remaining lectures and tutorial/workshop into a new 15-credit point physiology theory subject. Importantly, we retained the existing practicals, added a number of new skill-based practical tasks, and packaged this into a new physiology practicum, 15-credit point subject. This afforded us the opportunity to demark skills associated with the understanding of core theoretical information from a clearly distinct set of skills associated with scientific inquiry, scientific instrumentation, research data collection, analysis, and scientific writing. Another factor in our decision to separate the theory and practical subjects was that when the practicals were embedded within the theory subject, the weighting of assessments relating to the practicals contributed only 25% to the total subject grade. By introducing a new stand-alone physiology practical subject, we were able to increase the relative weighting of existing assessment tasks as well as introduce these new skill-associated tasks having significant assessment weightings.

After the subject redesign, some cohorts of students were required (or elected) to take the physiology theory subject only, whereas other cohorts of students were required (or elected) to take both the physiology theory and physiology practicum subjects concurrently. Therefore, this study set out to determine whether students who were concurrently enrolled in both physiology theory and practicum subjects performed better in some or all of the assessment tasks in physiology theory. Additionally, this study aimed to determine whether either of the above cohorts of students performed better in the assessment tasks related to the theory than the cohort of students who...
were previously enrolled in the old iteration of physiology (i.e., theory embedded with the practicum). The present study examined student census data from 2011, the first year of implementation of the two new redesigned subjects. As a comparison, student census data from 2009 when the physiology theory subject contained the embedded practicums were compared with both the 2011 cohorts.

The content of the physiology theory subject remained essentially the same: systems-based general physiology. However, the physiology practicum subject underwent substantial revision that aimed to have fewer practical activities requiring students to follow a “recipe” in a laboratory manual and more activities requiring students to identify the problem, explore strategies for solving it, and finally evaluate the solution. Interspersed with these practical activities, a series of skill development activities were also designed to explore the concepts of scientific writing (particularly the development of an abstract), methodology evaluation, and reporting of results. Furthermore, a series of prelaboratory hurdle requirements was developed consisting of prereading tasks and predictions on the to-be-conducted laboratory activity outcomes. Results from a previous study (11) have indicated that practical class activities are more effective when students are prepared before they conduct their experiments. Indeed, activities such as hypothesis testing and predictions have been widely used to promote active learning and improve student performance (2). As such, we hypothesized that the development of a new stand-alone physiology practicum subject would not only meet the stated objectives of the subject but would also enhance the physiology theory grades of those students who undertook both subjects within the one teaching period.

METHODS

Ethics. Publication of the material presented in this report was approved by the Faculty Human Ethics Committee (FHEC 12/147 and FHEC 12/170).

Students. In the year that this study was undertaken (2011), 208 students were enrolled in the physiology theory subject. Enrollment was 103 students in the physiology practicum subject. All students enrolled in the physiology practicum were also concurrently enrolled in physiology theory. Hence, 105 students were enrolled in the physiology theory subject but not the physiology practicum subject. The year that the one subject contained both physiology theory and practicum subjects had no difference in first-year grade point average. Hence, 103 students in the physiology theory subject. All students who did not attempt all assessments were not included in this study.

Students undertaking the subject were enrolled in three principal courses whose prerequisite scores before entry into the university were not substantially different. It is important to note that the group of students who were required to take both the physiology theory and practicum subjects had no difference in first-year grade point average than the other groups. The groups that were able to elect to take the practicum subject in addition to the theory subject also had no difference in their previous year grade point average. Thus, it was not simply the brighter students of year 1 who took both physiology subjects.

Assessment tasks in human physiology theory. The three assessment types in physiology theory were as follows: first, three online tests (OLTs; open book) based on the lecture material. Each test had a set duration, could be attempted only once, and consisted of five short answer questions requiring the application of core knowledge. The three tests collectively contributed 20% toward the total subject grade. Second, there were three group tests (closed book) based on tutorial/workshop case studies. Groups were self-selected and comprised up to five students. Each test consisted of one recall question, one related applied knowledge question, and one further related critical thinking question. The three tests collectively contributed 30% toward the total subject grade. Finally, there was an end-of-semester examination. The examination was based on lecture material and consisted of 40 multiple-choice questions (MCQs) and 5 essay-type [extended response (ER)] questions. The examination was worth 50% of the total subject grade.

The end-of-semester examination in 2009, when the theory subject contained embedded practicals, was essentially in the same format as that currently used.

Statistical analysis. A path model constructed in the form of a structural equation model was applied to ascertain the difference in end-of-semester examination results among the following three cohorts: the theory subject alone (cohort 1), theory and practicum (cohort 2), and theory embedded with practicals (cohort 3). As shown in generic form in Fig. 1 (8), the model could explicitly measure a cohort’s direct and indirect effects on the end-of-semester examination. The indirect effect of cohort on the examination was through the three intrasemester OLTs. Both the OLTs and examination are known as endogenous variables, whereas cohort is exogenous. The more familiar regression models are unable to cope with such a data structure where there are multiple endogenous variables in a model. A similar model, as shown in Fig. 2, was constructed to analyze the individual components of the examination results, namely, the MCQ component and the ER component. As analyzed with Stata 12.0 (Stata), all statistical tests were performed with 95% confidence intervals (equivalent to setting the level of significance at 5%).

RESULTS

Assessable components of the theory subject. The path model showed that students enrolled in both theory and practicum subjects performed significantly better in the individual OLTs, achieving a higher average mark of 1.02 (out of 20) compared with those who enrolled in the theory alone. Moreover, a better result in OLTs were significantly associated with a better examination result. When analyzed individually, the results for both components (MCQ and ER) were also significantly associated with the OLT results. However, a greater effect was seen with the ER component of the exam than with
practicum and theory concurrently perform statistically significantly better overall in the theory subject than the cohort of students taking physiology theory alone. When analyzed more deeply, our results showed that these students attained a significantly higher mark in the individual OLTs (1.02 marks of 20 marks total, 5.1% increase). Most interestingly, for each 1.02 mark improvement in the OLTs, a further 1.7-mark improvement (out of 50 marks total, 3.4% improvement) was attained in the end-of-semester examination ($P < 0.05$). This suggests that the intrasemester OLTs are a likely predictor of improved performance in the end-of-semester examination and, concomitantly, those students who do not exhibit an improved performance in the intrasemester OLTs will also show no significant improvement in the end-of-semester examination.

The fact that no significant differences in performance in group case study tests were observed is hardly surprising and a good control, as student groups were not formed on the basis of cohort and, as such, were made up randomly of members taking both physiology theory and the practicum as well as those taking theory alone.

The construct of the end-of-semester examination into a section of MCQs and a section of written essay-type questions, both with equal weighting, was developed on the basis that we wanted to assess both well-defined and problem-solving knowledge. It is well accepted that MCQs are best adapted for testing “lower-order” skills, whereas short-answer and/or essay tests are best adapted for testing “higher-order reasoning” skills (1). In the present study, when we teased out the differences in performance among the three cohorts in both of the two components of the end-of-semester examination, we found that students taking both theory and practical subjects concurrently performed significantly better in both the MCQ and ER components of the exam but, importantly, much more so in the ER component than students enrolled in the theory subject only. When students taking both theory and practical subjects were compared with those previously enrolled in the single theory/practicum-embedded subject, we found that those taking both theory and practical subjects concurrently performed significantly better in both the MCQ and ER components of the exam but not in the MCQ component. Finally, when we compared those students who took the theory subject only with those who were previously enrolled in the single theory/practicum-embedded subject, we found no significant differ-

**Table 1. Combined path analyses of examination, MCQ, and ER results**

<table>
<thead>
<tr>
<th>Path Analysis</th>
<th>Coefficient</th>
<th>95% Confidence Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohort → OLT</td>
<td>1.0240†</td>
<td>0.1381–1.9099</td>
</tr>
<tr>
<td>Theory subject alone* vs. theory and practical subject</td>
<td>1.6823†</td>
<td>1.3101–2.0545</td>
</tr>
<tr>
<td>OLT → exam</td>
<td>1.0454†</td>
<td>0.7533–1.3374</td>
</tr>
<tr>
<td>OLT → ER</td>
<td>2.0581†</td>
<td>1.5990–2.5172</td>
</tr>
<tr>
<td>Cohort → exam</td>
<td>1.2764</td>
<td>-2.6748 to 0.1219</td>
</tr>
<tr>
<td>Theory and practical subject* vs. theory with embedded practicals</td>
<td>-3.7707†</td>
<td>-5.8622 to –1.6792</td>
</tr>
<tr>
<td>Theory subject alone* vs. theory with embedded practicals</td>
<td>-0.5893</td>
<td>-1.6824 to 0.5039</td>
</tr>
<tr>
<td>Cohort → MCQ</td>
<td>1.3664</td>
<td>-2.8328 to 0.1000</td>
</tr>
<tr>
<td>Theory and practical subject* vs. theory with embedded practicals</td>
<td>0.0783</td>
<td>-0.6894 to 0.8461</td>
</tr>
<tr>
<td>Theory subject alone* vs. theory with embedded practicals</td>
<td>-5.8334†</td>
<td>-8.5466 to –3.1202</td>
</tr>
<tr>
<td>Cohort → ER</td>
<td>-1.2764</td>
<td>-2.6748 to 0.1219</td>
</tr>
<tr>
<td>Theory and practical subject* vs. theory with embedded practicals</td>
<td>1.2764</td>
<td>0.0783 to 2.4741</td>
</tr>
<tr>
<td>Theory subject alone* vs. theory with embedded practicals</td>
<td>-5.8334†</td>
<td>-8.5466 to –3.1202</td>
</tr>
</tbody>
</table>

MCQ: multiple-choice question; ER, extended response; OLT, intrasemester online test. *Reference point for coefficient analysis. †Statistically significant at 5%.
ences in their performance in either ER or MCQ components. Becker and Johnstone (1) reported in a study of these two forms of assessment in economics testing at the Australian tertiary level that there was no relationship between the two in terms of outcome. Indeed, Becker and Johnstone’s results imply that these testing genres measure different dimensions of knowledge. Assuming the same holds true in the assessment of physiology knowledge, it can then be extrapolated that students who undertake both theory and practicum subjects are more likely to develop skills in problem solving and a more developed or deeper understanding of the physiology theory than those undertaking the theory subject alone. This is supported in the present study by the results of the individual OLTs, which were particularly constructed (open book) to assess the student’s capacity to problem solve and/or apply their physiological theory knowledge, not simply to recall facts.

The difference in results between the cohort currently undertaking both physiology theory and practicum subjects and those that previously undertook the single embedded theory/practicum subject as well as the lack of difference between the cohort currently undertaking the theory subject only and those who previously undertook the single embedded theory/practicum subject might also be explained by different depth of learning. The practicals contained in the “old” physiology subject did not contain many of the skill-based practical classes that were introduced to develop deep learning skills. Also, the weighting of the assessment of the practical tasks was only a small proportion (25%) of the total assessment. Research clearly demonstrates that the importance a student places on assessment tasks are clearly dictated by their overall weighting (9). In our case, it can be argued that when the combined sum of all the assessment tasks associated with the practical activities contributed only 25% toward the total subject grade, less importance by students was given to the assessment tasks than when the assessment tasks associated with the practicals cover all 100% of the total assessment. Students may be divided into three main groups with regard to learning and studying: surface (memorizing details), deep (understanding material), and strategic (motivated by assessment) (3, 9, 10). The separation of physiology into theory and practicum components, thus allowing the implementation of highly weighted assessment tasks based on skill development, encourages the last two of the aforementioned learning strategies.

Conclusions. In 2010, a physiology theory and embedded practical subject (20 credit points) was divided into separate theory and practicum subjects (15 credit points each) after a change in university policy to reweight all second-year subjects at 15 credit points. This decision to increase rather than decrease the physiology presence in a science degree has resulted in better student learning for those students undertaking both subjects concurrently. Even though the practicum subject was constructed to develop a different set of intended learning outcomes compared with the theory subject, it is interesting to note that not only do students undertaking the practical subject develop these learning outcomes, but they are also able to perform better in assessments designed to test deep learning of the physiology theory and hence obtain, on average, a significantly higher mark in their physiology theory subject. The intrasemester OLTs are an accurate indicator of those students who attain these deep learning skills. Those who do not only perform better in the OLTs but are able to translate that improvement to the end-of-semester examination and, in particular, the ER component of that exam. Therefore, our model of intrasemester OLTs assessing physiology theory requiring deeper learning provides educators with the opportunity to identify students who are at risk of performing below expectations in the end-of-semester examination. Our experience demonstrates that requiring students to undertake a significant stand-alone practicum subject with highly weighted skill-based assessment tasks alongside the same discipline theory subject should be considered in all science curricula as it provides not only the attributes attainable by undertaking appropriately constructed practical tasks but also provides and encourages the skills and opportunity to develop a deeper learning of the theory underpinning the practical tasks.

DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

REFERENCES