Students integrate knowledge acquisition and practical work in the laboratory

E. I. Agüera, P. Sánchez-Hermosín, J. Díz-Pérez, P. Tovar, R. Camacho, and B. M. Escribano

1Department of Cellular Biology, Physiology and Immunology, University of Córdoba, Cordoba, Spain; and 2Department of Statistics, University of Córdoba, Cordoba, Spain

Submitted 2 February 2015; accepted in final form 4 June 2015

Agüera EI, Sánchez-Hermosín P, Díz-Pérez J, Tovar P, Camacho R, Escribano BM. Students integrate knowledge acquisition and practical work in the laboratory. Adv Physiol Educ 39: 209–213, 2015; doi:10.1152/advan.00019.2015.—The aim of the present work was to transfer a wider concept of teamwork and self-learning to the laboratory, encouraging students’ capabilities when seeking, acquiring, and processing knowledge. This educational innovation was carried out with a total of 38 students (fourth year of degree in Biology) in the area of physiology (Advances in Reproduction course) at University of Córdoba in Córdoba, Spain. The design of the project’s application methodology consisted of establishing a way in which problems would be tackled in the practical classes. For this purpose, the different tasks were set up so that students could relate them to the concepts learned in the theory classes. On the first day of class, the project was presented to the students. Groups of two to three students worked in the laboratory and set up an outline of the protocol of the practical work that they had done. This outline was performed individually and sent to the lecturers through a learning management system (Moodle). The teachers gave feedback and assessed student submissions. Upon finishing the course, students completed a survey. The project-based learning method promotes practical self-learning on the part of students. This methodology demonstrated to us that it stimulates a critical and self-critical capacity in students, both individually and in groups, and that writing didactic practical material helps students to enhance their theory knowledge. The experiment was a success in view of the scores obtained upon finishing the subject.

learning-based projects; educational innovation; advances in reproduction; group work

STUDENTS SHOULD BE STIMULATED by their teachers to be more confident in their self-directed learning (6). It is well known that active methodologies provoke students to acquire knowledge more effectively (10). Not only is the attitude of students in their adaptability to lifelong learning important, but equally the use of active learning strategies by teachers (24).

With a project-based learning method (PBL), students work actively, planning, implementing, and evaluating projects, which can be applied in the real world beyond the classroom (8, 14, 16, 17).

The students look for solutions to nontrivial problems since, according to Blumenfeld et al. (9), they learn to pose and refine questions, debate ideas, make predictions, design plans and/or experiments, compile and analyze data, establish conclusions, ask new questions, and communicate their ideas and discoveries to others.

The present study describes a teaching experiment carried out in the Advances in Reproduction course in the first term of the fourth year of the degree in Biology at the University of Córdoba. The fact of beginning a newly established course in the department led teachers to think that they did not want students to receive a passive learning experience in which the teacher gives explanations and the student merely listens. The idea was that, from the first day onward, students would receive an active teaching process in order for them to search for the meaning of what they had learned. Active teaching presumes that the students are active builders of their own knowledge and that, to each learning experience, they bring with them a store of information that, in some way, they use while they are endeavoring to understand (11).

PBL permits real-life situations to be simulated by means of a problem case proposed to the students, with the necessary information for understanding how to resolve it. Based on the method used by Alshuler and Bosch (1), the problem case was designed so that the students 1) do not dispose of all the information required for the setting up of the protocols, 2) make progress in the solution of the problem at the same time as new information is incorporated, and 3) are permitted to have multiple ideas and perspectives for their interpretation of the problem.

The present work aims to transfer to the laboratory a wider concept of team work and self-learning by fostering students’ abilities to search for, acquire, and process knowledge and compare sources of information. All this amounts to the writing of a protocol, which describes the set of technical procedures necessary to successfully perform practical sessions. In addition, the writing of such protocols is a transferable skill that can be used in other physiology courses. The employment of this active learning was evaluated through a survey as well as through personal interviews and group tutorials, which allowed us to gauge the satisfaction of students with this methodology.

METHODS

Students. The present study was composed of a total of 38 students (10 men and 28 women) from the area of physiology in the first term of the fourth year of the Biology degree who were enrolled in the optional subject “Advances in Reproduction.” The course was rated with 6 ECTS, meaning 60 h of face-to-face work and 90 h of nonface-to-face work. For the perspective of teacher effort, considering that the teachers did individual corrections scoring each protocol, the total hours spent were 0.5 h per student per protocol (19 h × 4 protocols = 76 h). Additionally, teachers answered student questions by e-mail and met students face to face, totaling approximately another 7 h of faculty effort. In summary, the amount of time invested to deploy this learning method was estimated to be 83 h more than for traditional lectures.

Due to the fact that this subject was delivered for the first time and all students took part in the new intervention, a historical control group did not exist. Similarly, as this was the first year that this subject was taught, there were no previous examinations with which to enable...
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a comparison of the results. We intended to divide students into two groups, one group to be examined with the traditional method and the other group with PBL. However, students did not agree with that intention. Taking this into account and given the small number of students, teachers decided not to divide the group of students. Protocol 1 was chosen instead as a baseline with which to compare within-subjects progress in the following protocols. Protocol 1 provided the learning framework that allowed students to reflect, use scientific language, and develop creativity. In other words, protocol 1 helped them achieve the necessary skills to effectively develop other protocols. The protocols increased progressively in difficulty, so that students could not go on to the next protocol without having done the previous protocol. Therefore, all students had to complete all protocols from protocols 1 to 4 sequentially.

The process. The research process was explained step by step as follows:

1. Presentation of the project to students and explanation of how it would contribute to their final grades. (Teachers)
2. Formation of groups (of 2–3 students/group) for practical class work and joint writing of protocol scheme. Practical class does not mean group-working activity. (Students)
3. Execution of protocols. Once students had finished the practical class, they set up their protocols individually and sent them to the teacher via the learning management platform Moodle. (Students)
4. Correction and scoring of the protocols. Protocols were corrected and sent back to the students so that they could learn from their mistakes. (Teachers)
5. Once the process was finished, results were statistically analyzed using version 18.0.3 of the SPSS package.

Protocols. A protocol is a demanding document that explains the systematic procedures to be carried out in each practical class. Each protocol should contain the objectives, the materials used, and an appendix in which photographs are included. Both the protocols and theory examination were scored on a scale from 0 to 10, with a score below 5 considered as a fail.

The following protocols were requested:

- Protocol 1: vaginal smear of a female mouse and its interpretation
- Protocol 2: collection and evaluation of mouse semen
- Protocol 3: vasectomy of a male mouse and ovariectomy and ovarian tissue transplant in a female mouse
- Protocol 4: collection of embryos directly from a mouse’s uterus (flushing)

Animals. The animals used in the present study were corpses of mice (male and female) Mus musculus not genetically modified, yielded by the Service of Animal Experimentation of the University of Córdoba. We used corpses because these practices can be learned without having to use live animals.

Survey. At the end of the course, all participants answered a perception of instruction survey (see Tables 2 and 3). Although not a formal control group, for comparison, the same student population had previously completed the same survey after another class. The previous course was led by the same instructors, with mostly the same students (n = 42), with the only major difference being the use of traditional teaching methods rather than PBL.

The survey was designed with eight questions and four degrees of satisfaction on a Likert scale (none, little, quite a lot, and a lot). The questions were as follows: 1) the teachers defined the project’s objectives with clarity; 2) the feedback received by the teacher in a protocol contributed to the elaboration of the following one; 3) I used complementary assistance to set up the protocols (teachers, colleagues, and bibliography); 4) the theory-practical synchronization contributed to fixing the acquisition of knowledge; 5) the practical activities helped toward the understanding of the subject; 6) the practical activities favored teamwork; 7) In general, I am satisfied with the work done; and 8) the whole process of self-directed learning provided satisfaction from the start.

Formal ethical committee approval for educational research is not required at the University of Córdoba; students gave informed consent to participate.

RESULTS

Results of protocols. First, the scores of the 38 students in the 4 practical protocols carried out were studied. Figure 1 shows a boxplot of each group of scores.

The distribution was asymmetrical for the scores of protocols 2 and 3, in which the median coincided with the third quartile, with a low outlier in protocol 2 and five low outliers plus a high scoring outlier in protocol 3. With respect to the boxplot of protocol 4, asymmetry and the lack of an upper whisker can be noted, due to the third quartile coinciding with the maximum possible score, which was 10.

Table 1 shows the means and SDs for the scores obtained by students in each of the protocols.

In protocol 1, the mean score was a B grade (7.7). This score progressively increased as the course advanced and students learned from the feedback and corrections made by the teachers, along with mutual help between peers (Table 1). Throughout the course, students gave very favorable informal feedback on the tutorials received and on the benefits of applying theory to practice when facing the writing of the protocols.

Subsequently, inferential statistics were used to assess the effectiveness of the procedure. For this purpose, a general mixed-effect linear model could be proposed. This would explain the score obtained in terms of the protocols and the students themselves, with the latter being a random factor. Nevertheless, the asymmetry of the data suggests lack of normality, confirmed by a Kolmogorov-Smirnov test (P < 0.01 for each protocol). In addition, the Levene test of homogeneity of variances based on the means was significant, taking 0.10 as level of significance.

For these reasons, it was decided to address the problem from the nonparametric point of view, using a repeated-measures approach. To analyze the evolution of the students’ performance, the scores obtained by them in protocol 1 were considered as a starting point. This was because the first score was obtained from the group when the didactic methodology had only just begun and its effects were not yet evident. The set of required abilities [i.e., to describe a protocol’s objectives,
planning, organization, formal writing style (clear and concisely), students notes, and supplementary material] was repeatedly examined across protocols 1–4 and on the final exam.

Friedman’s test that data from each of the four protocols were significatively nonhomogeneous (\( P < 0.001 \)). After this, multiple comparison between protocol 1 and each protocol of the rest were made through a Wilcoxon test with a Bonferroni correction; there were significative differences between the scores obtained in protocols 2–4 compared with protocol 1 as a control, and, in every case, \( P < 0.005 \).

Despite the objections mentioned on the parametric treatment of inference, ANOVA and subsequent post hoc Dunnett analysis led to the same conclusions.

**Results of theory examination and final course grades.** Figure 2 shows the scores obtained by the 37 students in the final theory examination, indicating that all students successfully completed the course (note that one student was absent from the final exam). Furthermore, Fig. 3 shows the grade distribution for the course including scores on the final exam and graded protocols, again indicating that all students successfully completed the program.

**Survey results.** The results of the survey taken from the students participating in the PBL method (Table 2) showed that most of them were highly satisfied with the objectives achieved in the practice exercises, with their self-learning and the ease with which they understood the subject. Students were satisfied with their progressive evolution in the setting up of protocols and were especially favorable regarding practice opportunity and faculty feedback. Faculty corrections, which commented on and discussed the aspects to be improved with a view to the development of the following protocol, were felt to be benefit to students in learning from their errors and in doing the following protocol better. For comparison, the survey referring to a previous course with a traditional teaching style showed a higher degree of dissatisfaction in all aspects surveyed (Table 3).

**DISCUSSION**

The aim of the present application of PBL was to enable students to work in groups, stimulating their capability to search for, acquire, and process knowledge. We agree with Molina Ortiz et al. (18) on the fact that this methodology develops constancy, observations, and attitudes not reached with traditional teaching. Although this technique is not new in teaching (3, 4, 19, 21, 22, 17), the teachers at the University of Córdoba wanted to adopt it since it is being used in other Spanish universities (18, 15, 17) to promote students’ creativity, individual responsibility, work in collaboration, critical capacity, decision making, efficiency, and ability to express personal opinions. In view of the results obtained in the final exam scores, students and faculty members considered that all these benefits had been acquired by the students.

Upon examining the results, we noted that the average scores of the students in the different protocols increased and also that significant differences were established as to how they went on improving their ability to prepare the protocols throughout the term.

One of the factors attributed by the authors to this fact was the interest demonstrated by the students who regularly attended the theory and practical classes, which permitted this learning method to give good results. However, in the literature consulted, authors like Sainz de Abajo et al. (23), who apply this technique in an optional course in technical engineering studies, did not obtain good results, precisely because the students enrolled in it did not attend classes assiduously. Furthermore, in 1992, Norman and Schmith (19), in their review of research on a similar approach of PBL, concluded that there was no evidence of the an increase in general problems-solving skills with PBL.

In the present study, teachers did one-to-one correction and scoring of the protocols and sent feedback to the students so that they could learn from their mistakes. Hattie (13), in a review of 87 meta-analyses of studies, explained that feedback makes a difference to student achievement. Likewise, Black and Williams (7) emphasized that feedback has consistent positive effects on learning compared with other aspects of teaching.

When we compared the sexes, we found that there was no significant difference in learning gains over time. Reynolds (22) did an initial experience of interprofessional PBL, taking into account a comparison of male and female students. This author also concluded that sex differences were not substantial, in agreement with our results.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol 1</td>
<td>7.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Protocol 2</td>
<td>8.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Protocol 3</td>
<td>8.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Protocol 4</td>
<td>9.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Total</td>
<td>8.4</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**Table 1. Means and SDs of the scores of the 38 students in the different protocols**

**Fig. 2. Student scores on the final theory examination.**

**Fig. 3. Distribution of final course grades.**
Circumstantial information from students indicated that both male and female students were equally satisfied with the new method. Additionally anecdotal reports from teachers indicated satisfaction with the process because all students implemented their protocols, presenting them on time and in the correct format, and students apparently learned from their errors, as demonstrated in the evolution of scores between protocols. All students enrolled took the final examination without any difficulty, and, as shown in Fig. 2, none of them failed it.

Student opinions were assessed with the survey taken at the end of the course. From the results obtained, 97% of the students were satisfied with the work done, 76% thought that this way of working helped them to understand the subject matter, and 73% considered that this type of work favored their self-learning abilities. Similarly, Anzar et al. (2) reported that from a survey taken related to skills acquired, 64% of the respondents perceived that the PBL methodology was highly important in self-learning. We agree with those authors in that PBL assists students in their learning and acquisition of skills with respect to traditional teaching methods. When we compared both surveys (PBL and traditional learning style), we noticed that 61% of the students were dissatisfied with the work done in the traditional course format, but no students expressed dissatisfaction with the PBL experience.

### Table 2. Results of the survey related to the problem-based learning method

<table>
<thead>
<tr>
<th>Question</th>
<th>None</th>
<th>A Little</th>
<th>Quite a Lot</th>
<th>A Lot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of students</td>
<td>%</td>
<td>Number of students</td>
<td>%</td>
</tr>
<tr>
<td>Question 1. The teachers defined the project’s objectives with clarity.</td>
<td>38</td>
<td>100</td>
<td>24</td>
<td>65.8</td>
</tr>
<tr>
<td>Question 2. The feedback received by the teacher in a protocol contributed to the elaboration of the following one.</td>
<td>6</td>
<td>15.8</td>
<td>32</td>
<td>84.2</td>
</tr>
<tr>
<td>Question 3. I used complementary assistance to set up the protocols (teachers, colleagues, bibliography, etc.).</td>
<td>4</td>
<td>10.55</td>
<td>21</td>
<td>55.3</td>
</tr>
<tr>
<td>Question 4. The theory-practice synchronization contributed to fixing the acquisition of knowledge.</td>
<td>9</td>
<td>23.7</td>
<td>29</td>
<td>76.3</td>
</tr>
<tr>
<td>Question 5. The practice activities helped toward the understanding of the subject.</td>
<td>5</td>
<td>13.1</td>
<td>33</td>
<td>86.4</td>
</tr>
<tr>
<td>Question 6. The practical activities favored teamwork.</td>
<td>1</td>
<td>2.6</td>
<td>37</td>
<td>97.4</td>
</tr>
<tr>
<td>Question 7. In general, I am satisfied with the work done.</td>
<td>6</td>
<td>15.8</td>
<td>32</td>
<td>84.2</td>
</tr>
<tr>
<td>Question 8. The whole process of self-directed learning provided satisfaction from the start.</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

### Table 3. Results of the survey related to traditional learning style

<table>
<thead>
<tr>
<th>Question</th>
<th>None</th>
<th>A Little</th>
<th>Quite a Lot</th>
<th>A Lot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of students</td>
<td>%</td>
<td>Number of students</td>
<td>%</td>
</tr>
<tr>
<td>Question 1. The teachers defined the project’s objectives with clarity.</td>
<td>25</td>
<td>65.8</td>
<td>13</td>
<td>34.2</td>
</tr>
<tr>
<td>Question 2. The feedback received by the teacher in a protocol contributed to the elaboration of the following one.</td>
<td>18</td>
<td>47.4</td>
<td>17</td>
<td>44.7</td>
</tr>
<tr>
<td>Question 3. I used complementary assistance to set up the protocols (teachers, colleagues, bibliography, etc.).</td>
<td>11</td>
<td>28.9</td>
<td>29</td>
<td>76.3</td>
</tr>
<tr>
<td>Question 4. The theory-practice synchronization contributed to fixing the acquisition of knowledge.</td>
<td>16</td>
<td>42.1</td>
<td>22</td>
<td>57.9</td>
</tr>
<tr>
<td>Question 5. The practice activities helped toward the understanding of the subject.</td>
<td>17</td>
<td>44.7</td>
<td>6</td>
<td>15.8</td>
</tr>
<tr>
<td>Question 6. The practical activities favored teamwork.</td>
<td>27</td>
<td>71.1</td>
<td>11</td>
<td>28.9</td>
</tr>
<tr>
<td>Question 7. In general, I am satisfied with the work done.</td>
<td>23</td>
<td>60.5</td>
<td>15</td>
<td>39.5</td>
</tr>
<tr>
<td>Question 8. The whole process of self-directed learning provided satisfaction from the start.</td>
<td>21</td>
<td>55.3</td>
<td>17</td>
<td>44.7</td>
</tr>
</tbody>
</table>
Conclusions. The following conclusions were drawn from the results of the present study:

1. There was an increase in performance between protocols. This means that students gradually acquired their skills of how to use scientific language, how to plan their work, summarized the knowledge acquired in class, and reinforcing their self-learning.

2. When we comparing the sexes, no difference between male and female students was found.

3. Considering the final results of the subject, both students and teachers felt that the experiment was a success.

4. In general, PBL promotes practical self-learning on the part of the student.

ACKNOWLEDGMENTS

The authors are grateful to all participants of the study.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS


REFERENCES