Peer instruction enhanced student performance on qualitative problem-solving questions

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There has been remarkable progress in our understanding on how people learn. It is now clear that concept construction requires active processing of information. That is, we understand and remember the information we think about (8)! However, processing information requires time. Faculty members must be realistic about the amount of time required to learn complex concepts and provide the time needed to achieve the goal (5). Students need time to explore the underlying concepts and to generate connections to other information. Students must have time to “grapple” with specific information relevant to the topic. Thus, learning cannot be rushed; the complex cognitive activity of information integration requires time (4).

However, students attending our Physiology course are in class 5 h/wk. This computes to ~2.4% of the total hours in a student’s week. Herein lies the problem: How do we provide time for information processing during this limited class time (8)? One way is to use qualitative problems (14, 15) in a peer instruction format (12, 13). These problems require a qualitative prediction (increase/decrease/no change) about the response of a physiological system to a perturbation. Qualitative problems require integration of multiple concepts; however, the problems can be answered quickly with single, best multiple-choice questions. These are important considerations because one of the most important factors influencing learning is what the student already knows. The students must link new information to concepts they already possess (8). This process is critical for solving novel problems. Peer instruction is a cooperative learning technique that may promote this process. Therefore, we tested the hypothesis that peer instruction enhances the students’ performance on qualitative problem-solving questions. To test this hypothesis, qualitative problems were included in a peer instruction format during our Veterinary Physiology course.

METHODS

Design. We borrowed concepts from Lymna (11) and Mazur (13) peer instruction activities to promote student involvement in the learning process and test the hypothesis that peer instruction enhances student performance on qualitative problem-solving questions.

Procedures. This peer instruction, active-learning technique was implemented during the Physiology class (Fisiología No. 423) at the Facultad de Ciencias Veterinarias, Universidad Nacional de La Plata, La Plata, Argentina. The class consisted of 114 veterinary medical students. The class was lecture based, and the peer instruction technique was used for 10 classes involving cardiovascular, respiratory, and renal physiology. Each class of 90 min was divided into four to six short presentations of 15–20 min each. Each short presentation was followed by a qualitative problem-solving scenario that could be answered with a one-question, multiple-choice quiz. All students were allowed 1 min to think and to record their answers. Subsequently, students were allowed 1 min to discuss their answers with classmates (2–3 students/group). Students were then allowed to change their first answer if desired, and both answers were recorded. Students were instructed to provide reasons for their answers and to convince their peers that their answers were correct. In this format, the students had two roles: as a teacher, explaining the rationale for their answer; and as a student, listening to the reasoning for their peers’ answer. Finally, the instructor and students discussed the answer.

The questions were qualitative problem-solving scenarios generated by M. J. Giuliodori using the format provided by Michael and co-workers (see Appendixes A–C) (14, 15). The qualitative problem-solving scenarios asked for a qualitative prediction (increase/decrease/no change) about the response of a system to a perturbation; for example, If the heart is dener-
vated, what change, if any, will occur to heart rate (will it increase, decrease, or stay the same)? (14). Specifically, the questions posed conceptual problem-solving scenarios that required the integration of multiple concepts but were answered with single, best multiple-choice questions. In addition, tables were used, instead of multiple-choice questions, when more than one prediction was required (see Appendixes A–C); for example, Predict how cutaneous blood flow, shivering, and sweating will be affected at the onset of a fever (15).

Statistical analysis. All results are presented as means ± SE, and significance was set at the \( P < 0.05 \) level. To determine the effect of peer instruction on student performance on qualitative problem-solving questions (see Fig. 1), we used a Student’s paired \( t \)-test to compare responses obtained when the students solved problems as individuals with responses obtained when the students solved problems in collaboration with peers (peer instruction).

To determine which students changed their individual response (see Fig. 2), we used a Kruskal-Wallis nonparametric, one-way ANOVA. Once statistical significance was established, post hoc analysis was performed with a Student-Newman-Keuls test. Finally, to compare the positive effects (individual incorrect responses changed to peer-instructed correct responses) with negative effects (individual correct responses changed to peer-instructed incorrect responses), we used a Mann-Whitney rank-sum test (see Fig. 3). Significance was set at the \( P < 0.05 \) level.

RESULTS

Figure 1 presents the percentage of correct responses when the students solved problems as individuals and when the students solved the same problems in collaboration with peers. As individuals, the students responded correctly 59.3 ± 0.5% of the time. In sharp contrast, in collaboration with peers, the students solved the same problem correctly 80.3 ± 0.4% of the time. This 21% increase was statistically significant \( (P < 0.001) \).

Figure 2A presents the percentage of correct individual responses that did not change (correct to same correct) or changed to incorrect responses (incorrect to incorrect) after peer instruction. In the group of students having correct individual responses (~60% of the total population), 93.5% did not change their response after peer instruction (no effect). However, 6.5% changed their responses to incorrect responses (negative effect). To determine which students changed their individual response (see Fig. 2), we used a Student-Newman-Keuls test. Finally, to compare the positive effects (individual incorrect responses changed to peer-instructed correct responses) with negative effects (individual correct responses changed to peer-instructed incorrect responses), we used a Mann-Whitney rank-sum test (see Fig. 3). Significance was set at the \( P < 0.05 \) level.

Figure 2B presents the percent of incorrect individual responses that changed to correct responses (incorrect to correct), changed to a different incorrect response (incorrect to incorrect), or did not change (incorrect to same incorrect) after peer instruction. In the group of students having individual incorrect answers (~40% of student population), 56.8% changed their initial incorrect response to a correct response after peer instruction (positive effect), 35.9% did not change (incorrect to same incorrect, no effect), and 7.3% changed to another incorrect response (no effect). One-way nonparametric ANOVA revealed significant group effects \( (P < 0.001) \). Post hoc analysis revealed that fewer students change their responses from correct to incorrect (6.5%) than from incorrect to correct (56.8%, P < 0.05). Thus, most correct students (93.5%) did not change their individual responses; however, many incorrect students did (64.1%). Taken together, these data document that it is easier to convince someone who is incorrect than someone who is correct.

Fig. 1. Effect of peer instruction on students’ qualitative problem-solving skills. Without peer instruction (individual), the students solved problems correctly 59.3 ± 0.5% of the time (mean ± SE). In contrast, when students were allowed to collaborate with classmates (peer instruction), the students solved the problems correctly 80.3 ± 0.4% of the time. *\( P < 0.001 \), individual vs. peer instruction.

Fig. 2. A: percentages of correct individual responses that did not change (correct to same correct) or changed to incorrect responses (correct to incorrect) after peer instruction. In the group of students having correct individual responses (~60% of the total population), 93.5% did not change their response after peer instruction (no effect). However, 6.5% changed their responses to incorrect responses (negative effect). B: percentages of incorrect individual responses that changed to correct responses (incorrect to correct), changed to a different incorrect response (incorrect to incorrect), or did not change (incorrect to same incorrect) after peer instruction. In the group of students having individual incorrect answers (~40% of student population), 56.8% changed their initial incorrect response to a correct response after peer instruction (positive effect), 35.9% did not change (incorrect to same incorrect, no effect), and 7.3% changed to another incorrect response (no effect).
answers (~40% of student population), 56.8% changed their initial incorrect response to a correct response after peer instruction (positive effect), 35.9% did not change (incorrect to same incorrect, no effect), and 7.3% changed to another incorrect response (no effect). Of the student population, only 4% showed a negative change (individual correct answers to peer-instructed incorrect answers). However, 22.4% showed a positive change (individual incorrect answers to peer-instructed correct answers, $P < 0.001$).

Figure 3 compares the positive effects (individual incorrect responses changed to peer-instructed correct responses) with negative effects (individual correct responses changed to peer-instructed incorrect responses). Only 4% of the students had a negative change (individual correct response to peer-instructed incorrect responses). In contrast, 22.4% of the students had a positive change (individual incorrect response to peer-instructed correct responses). Post hoc analysis revealed that the positive effects were higher than the negative effects (22.4% vs. 4.0%, $P < 0.001$).

Students’ perceptions regarding the peer instruction activity are presented in Table 1. One hundred four students (of 114 students total) returned the completed questionnaire (91.2% response rate). The students reported that the peer instruction methodology was simple and helped them to better understand the topics. The students reported that the level of discussion was high and the immediate feedback was helpful. Finally, the students enjoyed the methodology and recommended it for other courses.

**DISCUSSION**

In this work, we examined the effect of peer instruction, a pedagogical tool that increases student interactions with each other and with the instructor, on student performance on qualitative problem-solving questions. The main finding was that peer instruction increased student performance on qualitative problem-solving questions. Specifically, there was a 35% improvement in correct responses to qualitative problems after discussions with peers (absolute gain: 21 percentage units, $P < 0.001$; Fig. 1). Similar results have been reported by other investigators. For example, Crouch and Mazur (7) observed significant increases in conceptual problem-solving skills involving physics scenarios over a 10-yr period of peer instruction experience. Similarly, we (17) recently reported that peer instruction increased medical student performance on quizzes. Furthermore, collaborative testing, a similar peer instruction procedure, also increased medical student performance on quizzes (16, 18). Similarly, peer instruction as well as collaborative testing increased undergraduate student performance on exams and increased student retention of previously learned information (5, 6). Specifically, performances on quizzes and retention of previously learned information were significantly higher when students completed exams in groups rather than when they completed exams individually (5, 6). Importantly, we (5) also documented that peer instruction enhanced meaningful learning (the students’ ability to solve novel problems).

The new finding from this study is that peer instruction enhanced student performance on qualitative problem-solving questions. Qualitative problems require the integration of multiple concepts. Thus, peer instruction provides a learning experience that leads to the ability to extend what has been learned in one context to new contexts (2, 20). All learning experiences can appear equivalent when measures of learning are focused on the ability to repeat previously taught facts. However, quality learning experiences require the ability to extend what has been learned in one context to new contexts. Quality learning experiences require time to allow for practice. Faculty members must be realistic about the amount of time required to learn complex concepts and provide the practice time to achieve the goal. Students need time to explore underlying concepts and to generate connections to other information. Students must have time to “grapple” with specific information relevant to the topic. Thus, learning cannot be rushed;

![Fig. 3. Effect of peer instruction on the way students changed their responses (positive change vs. negative change). Of the student population, only 4% showed a negative change (individual correct answers to peer-instructed incorrect answers). However, 22.4% showed a positive change (individual incorrect answers to peer-instructed correct answers, $P < 0.001$).](image-url)

**Table 1. Student perceptions regarding the PI activities**

<table>
<thead>
<tr>
<th>Questionnaire Items</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The methodology of PI was clear and easy to follow.</td>
<td>3.80±0.09</td>
</tr>
<tr>
<td>2. The methodology of PI was interesting and enjoyable.</td>
<td>3.84±0.08</td>
</tr>
<tr>
<td>3. The methodology of PI helped me to better understand the topics.</td>
<td>3.91±0.09</td>
</tr>
<tr>
<td>4. The levels of discussion with peers and instructor were high.</td>
<td>3.75±0.09</td>
</tr>
<tr>
<td>5. The immediate feedback given by discussions with peers and instructor was positive.</td>
<td>3.92±0.08</td>
</tr>
<tr>
<td>6. Other faculty members should include PI in their courses.</td>
<td>3.72±0.10</td>
</tr>
</tbody>
</table>

Data are shown as means ± SE; $n = 104$ students who returned the completed questionnaire (91.2% response rate) regarding the peer instruction (PI) activities. Responses were on a 5-point scale, where 1 was completely disagree, 2 was disagree, 3 was neither agree nor disagree, 4 was agree, and 5 was completely agree.
the complex cognitive activity of information integration requires time (4). Importantly, peer instruction provides the time for students to test existing knowledge and apply it to novel situations in a safe, supportive environment. This quality learning experience allows students to evaluate their concepts and experiences while providing feedback about their progress.

A previous study (13) has shown that students obtain optimal benefits of peer instruction when the percentage of correct individual responses is between 35% and 70%. Specifically, when the percentage of correct individual responses is too low (<35%) or too high (>70%), there is little improvement. For example, when the percentage of correct individual responses is too low (<35%), most of the students have not obtained sufficient understanding of the concept to have meaningful discussions. In contrast, when the percentage of correct individual responses is too high (>70%), there is less room for improvement (13). In this study, the percentage of correct individual responses (59.3 ± 0.4%) was within the range for optimal improvement (13).

The beneficial effects of peer instruction are due, in part, to two major factors. First, student attention decreases with each passing minute during sustained lectures. Importantly, peer instruction activities increase attention by actively involving students in problem-solving activities. Furthermore, sustained lectures appeal only to auditory learners and tend to promote lower-level learning of factual information (10, 18). Finally, sustained lecturing assumes that all students learn the same information at the same pace (9). Rowe (19) reported that pausing every 15 min during a lecture increased students’ attention and retention.

Second, the value of peer instruction derives from the student generating explanations for their answers. Students obtain benefits when they generate their own explanations (“self-explanation”) for their new knowledge (3) and when they explain their reasoning to classmates, that is, when the learner acts as a teacher. Thus, “the best way to learn something is to teach it,” because teaching requires the generations of explanations, both for oneself and for the learner (14). All of us who teach have experienced and understand the true meaning of this concept.

In this study, only 6.5% of the students with individual correct responses changed their answers after peer discussion to incorrect responses. In sharp contrast, 64.1% of the students with individual incorrect responses changed their answers after peer discussion. Thus, most of the students who changed their responses changed to a correct answer to correct responses (56.8%), whereas a small portion changed to an incorrect answer (7.3%, P < 0.05; Fig. 2). Specifically, 22.4% of the student population changed their responses in a positive way (from incorrect to correct answers), whereas only 4.0% of the student population changed their responses in a negative way (from correct to incorrect answers, P < 0.001; Fig. 3). Taken together, the magnitude of the peer instruction positive effect was 5.6 times higher than the magnitude of the peer instruction negative effect. Therefore, the beneficial effects of peer instruction on students’ performance were observed in the group of students having individual incorrect answers (“weaker students”) (Fig. 3). These results are in agreement with reports by Crouch and Mazur (7). These authors reported that it is much easier to change the mind of someone who is wrong than it is to change the mind of someone who has selected the correct answer for the right reasons (13). Thus, there is always an increase and never a decrease in the number of correct answers (solutions) after discussion with classmates.

Faculty members are often reluctant to incorporate active learning activities in class. The reasons most often advanced for not including these active learning activities include not being able to cover as much content and the excessive preparation time required for devising strategies promoting active learning (1). However, as stated by Mazur (13), using time for peer instruction greatly improves the student’s level of understanding with relatively little effort and no capital investment. In addition, the instructor has several important roles during the process. For example, the instructor must model appropriate social skills, including listening and providing constructive feedback or eliciting more indepth responses through probing questions. The instructor must also reinforce these positive behaviors by publicly commenting on the ways students use them effectively (5).

Student perceptions regarding the peer instruction activities are in agreement with previous work (5, 6, 16, 17). Students appreciated the interactions with peers and with the instructor. This interaction provided immediate feedback, which is not possible during the traditional lecture format. The students reported that peer instruction facilitated their learning of the topics. In this content, students were seen to be enthusiastically engaged in content-based discussions, giving support to their choices. Finally, students enjoyed this learning experience and recommended it for other courses.

In conclusion, pausing four to six times during a 90-min class to allow peer instruction of qualitative problems enhanced the students’ performance on qualitative problem-solving questions.

Appendix A: Samples of Assessed Cardiovascular Questions

1. Predict (increase/decrease/no change) what would happen to the velocity of blood flow through systemic vessels if you provide a medication causing smooth muscle contraction:
   A. Increase (correct)
   B. Decrease
   C. No change

2. Predict (increase/decrease/no change) what would happen to the resting membrane potential in cardiac muscle cells if the extracellular K+ concentration increases:
   A. Increase
   B. Decrease (correct)
   C. No change

3. Predict (increase/decrease/no change) what would happen to cardiac output if you provide a medication causing smooth muscle relaxation:
   A. Increase
   B. Decrease (correct)
   C. No change

4. Predict (increase/decrease/no change) what would happen to stroke volume, end-diastolic volume, and cardiac output if afterload increased:

<table>
<thead>
<tr>
<th></th>
<th>Stroke volume</th>
<th>End-diastolic volume</th>
<th>Cardiac output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
</tbody>
</table>
5. Predict (increase/decrease/no change) what would happen to the volume of blood returning to the heart through the veins if right atrial pressure (central venous pressure) increased:
   A. Increase
   B. Decrease (correct)
   C. No change

6. Predict (increase/decrease/no change) what would happen to tissue fluid formation if you provide a medication causing smooth muscle contraction in veins:
   A. Increase (correct)
   B. Decrease
   C. No change

Appendix B: Samples of Assessed Respiratory Questions

1. Predict (higher/lower/the same) how the tidal volume of a horse immediately after a race would compare with its tidal volume at rest:
   A. Higher (correct)
   B. Lower
   C. The same

2. Predict (increase/decrease/no change) what will be the effect on alveolar ventilation of breathing at higher frequency while keeping the same respiratory volume:
   A. Increase
   B. Decrease (correct)
   C. No change

3. Predict (increase/decrease/no change) what would happen to functional residual capacity in a lung disease leading to emphysema:
   A. Increase (correct)
   B. Decrease
   C. No change

4. Predict (increase/decrease/no change) what would happen to airflow resistance if you provide a medication causing smooth muscle relaxation:
   A. Increase
   B. Decrease (correct)
   C. No change

5. Predict (increase/decrease/no change) what would happen to arterial Po₂ in a dog breathing 100% oxygen (oxygen therapy):
   A. Increase (correct)
   B. Decrease
   C. No change

6. Predict (increase/decrease/no change) what would happen to ventilation and perfusion in a dog having its right pulmonary artery blocked:

<table>
<thead>
<tr>
<th></th>
<th>Response</th>
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</thead>
<tbody>
<tr>
<td>Right lung ventilation</td>
<td>Decrease</td>
</tr>
<tr>
<td>Left lung ventilation</td>
<td>No change</td>
</tr>
<tr>
<td>Left lung perfusion</td>
<td>No change</td>
</tr>
</tbody>
</table>

Appendix C: Samples of Assessed Renal Questions

1. Predict (increase/decrease/no change) what would happen to the glomerular filtration rate, renal blood flow, and glomerular capillary pressure during efferent arteriolar vasoconstriction:

<table>
<thead>
<tr>
<th></th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glomerular filtration rate</td>
<td>Increase</td>
</tr>
<tr>
<td>Renal blood flow</td>
<td>Decrease</td>
</tr>
<tr>
<td>Glomerular capillary pressure</td>
<td>Increase</td>
</tr>
</tbody>
</table>

2. Predict (higher/lower/the same) how urine osmolarity would be compared with plasma osmolarity if you provide a medication blocking the 2Cl⁻-Na⁺-K⁺ cotransporter (i.e., furosemide):
   A. Higher (correct)
   B. Lower
   C. The same

3. Predict (higher than 1/lower than 1/equal to 1) the fractional excretion of a drug that is both filtered and secreted (with no reabsorption):
   A. Higher than 1 (correct)
   B. Lower than 1
   C. Equal to 1

4. Predict (increase/decrease/no change) what would happen to the urine concentration capacity in a dog given a low-protein diet:
   A. Increase
   B. Decrease (correct)
   C. No change

5. Predict (increase/decrease/no change) what would happen to plasma Na⁺ concentration, total body Na⁺ content, plasma K⁺ concentration, and total body K⁺ content if you provide a medication with an aldosterone antagonistic effect:

<table>
<thead>
<tr>
<th></th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Na⁺ concentration</td>
<td>No change</td>
</tr>
<tr>
<td>Total body Na⁺ content</td>
<td>Decrease</td>
</tr>
<tr>
<td>Plasma K⁺ concentration</td>
<td>Increase</td>
</tr>
<tr>
<td>Total body K⁺ content</td>
<td>Increase</td>
</tr>
</tbody>
</table>

6. Predict (increase/decrease/no change) what would happen to urine elimination of titratable acids if the organic load of metabolic acids increases:
   A. Increase (correct)
   B. Decrease
   C. No change

7. Predict (increase/decrease/no change) what would happen to both the volume and osmolarity of extra- and intracellular fluid compartments if you provide a hypertonic saline solution (i.e., 7.5% NaCl) intravenously:

<table>
<thead>
<tr>
<th></th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extracellular fluid compartment</td>
<td>Increase</td>
</tr>
<tr>
<td>Intracellular fluid compartment</td>
<td>Decrease</td>
</tr>
</tbody>
</table>

GRANTS

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REFERENCES