HOW WE TEACH | Generalizable Education Research

A large drawing of a nephron for teaching medical students renal physiology, histology, and pharmacology

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Robinson PG, Newman D, Reitz CL, Vaynberg LZ, Bahga DK, Levitt MH. A large drawing of a nephron for teaching medical students renal physiology, histology, and pharmacology. Adv Physiol Educ 42: 192–199, 2018; doi:10.1152/advan.00022.2017.—The purpose of this study is to see whether a large drawing of a nephron helped medical students in self-directed learning groups learn renal physiology, histology, and pharmacology before discussing clinical cases. The end points were the grades on the renal examination and a student survey. The classes in the fall of 2014 and 2015 used the drawing, but not those of 2012 and 2013. The Charles E. Schmidt College of Medicine at Florida Atlantic University is a newly formed Florida medical school, which enrolled its first class in the fall of 2011. The school relies on self-directed problem-based learning in year 1 and changes over to a case inquiry method in the latter part of year 1 and throughout year 2. At the start of the renal course, each student group received a poster of a nephron with the objective of learning the cell functions of the different nephron parts. During the first year of using the drawing, there was no improvement in grades. After a student suggested adjustment to the drawing, there was a statistically significant difference in the total test score in the second year ($P < 0.001$). An unexpected finding was lower grades in all 4 yr in the area of acid-base balance and electrolytes compared with the other four areas tested. In the survey, the students found the drawing useful.

INTRODUCTION

The purpose of this article is to describe a method of teaching medical students about renal histology, physiology, and pharmacology in the context of student learning groups. A recently conducted survey of United States internal medicine subspecialty fellows (4) found that almost one-third of the respondents thought renal physiology was the most difficult course in medical school with acid-base, water balance, and electrolyte disorders being the most difficult topics to understand. In an effort to create a more productive environment, student groups were given a large drawing (36 in. $\times$ 53 in.) of a nephron and told to fill in the channel and transporter pathways and show the sites of action for various medications. The drawing and the associated learning objectives were called Project Nephron. The project was undertaken at the Charles E. Schmidt College of Medicine (CESCOM) at Florida Atlantic University (FAU), which is a new medical school in Boca Raton, Florida, that emphasizes small-group, self-directed learning in accordance with the Liaison Committee on Medical Education (LCME) standards (5). It accepted its first entering class of 64 students in the fall of 2011, and it became fully LCME accredited in June 2015.

The school uses an integrated curriculum with small student groups participating in active learning as well as didactic lectures. Prince (7) reviewed active learning and discussed the three main types that engage the students, which include: 1) collaborative learning; 2) cooperative learning; and 3) problem-based learning (PBL). Collaborative learning is where students work together in small groups toward a common goal and learning is through interaction rather than solitary study. Cooperative learning is where students pursue common goals with a focus on cooperation rather than competition, while being assessed individually. The third type is PBL, of which the case inquiry method (IQ) is a variant. In both PBL and IQ, clinical cases are introduced at the beginning of the cycle, and the students must develop their own objectives for each case. In PBL, each student researches one objective and presents it to the class. In IQ, all of the students research all of the objectives and participate in the subsequent case discussion. In the first semester, the freshmen take a course called Fundamentals of Biomedical Science, which provides them with a broad foundation in medical sciences with a concurrent course in human anatomy. In addition, the 64 students are randomly divided into 8 self-directed learning groups that are composed of 8 students and 1 faculty facilitator and meet for 2 h three times a week. The purpose of these groups is to discuss clinical cases using PBL, as is done at McMaster University medical school (6). After the neuroscience course, which is the first course in the second semester of the freshman year, the students switch from PBL to an IQ format, which is modeled on the one used at Case Western Reserve University School of Medicine (2, 8). The IQ format lasts through the entire sophomore year, in addition to the interdisciplinary organ systems blocks taught by the science and clinical faculty.
For the sophomore classes in the fall of 2012 and 2013, the IQ cases began on the first day of the organ block before the students had any lectures in renal physiology. The pulmonary course immediately preceded the renal course, which gave the students some knowledge of acid-base balance. In their renal course feedback, the students suggested the course could be improved if they were taught some renal anatomy and physiology before they started the clinical cases. In response to the suggestion, a large-scale drawing of a nephron was created (Fig. 1) and given to the sophomore students in the fall of 2014. The drawing and the associated learning objectives were called Project Nephron. The drawing added a visual dimension to learning the histology and function of the nephron. The feedback from the 2014 students resulted in leaving the renal tubular epithelial cells in the drawing, but deleting the transporter and channel pathways, resulting in a slightly different drawing being used in the fall of 2015 (Fig. 2). The drawing introduced the students to the function of the nephron as well as the sites of action for pharmacological agents. The students were advised to use Eaton and Pooler (3) as well as Boron and Boulpaep (1) as references. After the drawing was completed, it remained posted in the small-group learning rooms and was easily available for the discussion of subsequent cases. It served as a nephron blueprint from which the students could visualize and learn the various functions of the nephron.

The students from the fall of 2012 and 2013 served as control groups in evaluating the usefulness of Project Nephron, whereas the students from the fall of 2014 and 2015 were the experimental group. The renal examination test scores were available for all four groups to determine if Project Nephron helped the students in the fall of 2014 and 2015 improve their learning of the function of the nephron. These students were also given a survey to see if they liked using the drawing and if they thought it was a useful learning tool. This study aims to answer two questions: 1) did the drawing help the medical students learn nephron physiology, histology, and pharmacology; and 2) did the students find using the drawing helpful?

Fig. 1. This drawing of the nephron was the first one given to the students in the fall of 2014. The nephron shows the glomerulus with the afferent and efferent arterioles, juxtaglomerular apparatus, proximal convoluted tubule, loop of Henle, distal convoluted tubule, and the collecting duct. The tubular epithelial cells have the spaces for the channels and transporters drawn in, but not labeled. The glomerulus is represented by an electron micrograph showing the podocytes, endothelial cells, and the glomerular basement membrane. [Drawn by C. L. Reitz, adapted from Vander Renal Physiology (8th Ed.) (3) with permission from McGraw-Hill Education. Inset image by Marilyn Farquhar/CC BY 3.0. http://www.cellimagelibrary.org/images/37181.]
METHODS AND MATERIALS

This is a retrospective study based on feedback data that was collected from students with the intention of improving the renal course. A letter of consent exemption for this study was granted by FAU’s Institutional Review Board.

Materials Given to the Students

One of the authors (CLR) drew an idealized nephron with the presence of glomerular and tubular cells (Fig. 1). This drawing included the unlabeled channels and the ion transporters. Each of the eight learning groups received one large drawing of the nephron, and each student received a small one (8 1/2 × 11 in.). It was given to the sophomore students in the fall of 2014, along with the following objectives:

- Describe the function of the different parts of the nephron (glomerulus, juxtaglomerular apparatus, proximal convoluted tubule, loop of Henle, distal convoluted tubule, and the collecting duct), and name the electrolyte pumps (transporters) in the various parts of the tubule.
- Describe the mechanism of action for diuretics, including carbonic anhydrase inhibitors (example, acetazolamide), loop diuretics (example, furosemide), potassium sparing diuretics (example, spironolactone), and thiazide diuretics.
- Describe how the kidney regulates the electrolytes, water, and acid-base balance.
- Describe the location and mechanism of action of antidiuretic hormone (or vasopressin).

The students spent two sessions with the nephron drawing. The first session was 50 min in duration, and the purpose was for the students to divide up the functions of the nephron among themselves. At the next session, each student described his or her assigned nephron function to the small group. The second session was 2 days later, and it consisted of two sequential 50-min sessions with a break in the middle. The students discussed the functions of the nephron and inserted labels on the transporters and channels of the tubular cells. At the end of the second session, each student received a drawing of the nephron with the answers in place (Fig. 3). With the help...
of the answer sheet, the students filled in their large drawing, posted it in the room, and used it as a reference for subsequent IQ cases. Based on student feedback, the 2015 drawing was slightly different (Fig. 2). The purposeful omission of channel and transporter pathways required the students to make a greater effort to understand the function of the renal tubular epithelial cells.

Renal Course Curricular Changes from 2012 to 2015

Between the two groups of students who received the drawings and those who did not, the course of instruction for all 4 yr was similar. The lectures and IQ cases changed slightly over the 4 yr. In each of the years 2013 and 2014, one of the IQ cases was dropped, and a more appropriate one was added to give the students a broader understanding of renal tubular and glomerular diseases. In all 4 yr, the students had a take-home exercise of four renal cases with hereditary renal tubular dysfunction, such as Gitelman syndrome. In 2012 and 2013, the students kept a drug log where they listed each medication in the course and its mechanism of action. The log was discontinued in 2014. A 2-h virtual microscopic pathology laboratory session was introduced in 2013. The students in 2012 did not have the pathology laboratory, but the students from 2013 through 2015 did. The simulation center patient exercise and the dialysis center visit remained the same for all 4 yr. The differences in the renal examinations from year to year are discussed below.

Assessment Methods

Customized examination from the National Board of Medical Examiners. The value of Project Nephron was assessed in two ways: 1) a comparison of the renal examination score for all 4 yr; and 2) a survey given to the sophomore students who took the course in the fall of 2014 and 2015. The medical students in all 4 yr were tested at the end of the 4-wk renal course with a customized examination from the National Board of Medical Examiners. The questions used to create the examination are retired ones from the STEP 1 examination of the United States Medical Licensing Examination. The questions measured the overall mastery of the subject but also reported on the following five areas: 1) acid-base and/or electrolytes; 2) renal histology; 3) pharmacology; 4) physiology; and 5) system pathology. All of the examinations were created by one of the authors (PGR). Since the creation of the first examination in...
In the fall of 2012, the core of the examinations has remained relatively unchanged, although some questions have been dropped and new ones added. The questions are of both the recall and process types. The number of questions on each examination ranged from a high of 90 to a low of 75. The examinations were timed at 72 s per question. The examinations were graded on a score of 0–100 points.

Survey. The surveys for Project Nephron were given to the sophomore students in the fall of 2014 and 2015 after 3 1/2 wk of a 4-wk course. The survey for the fall of 2015 was slightly different from the one in the fall 2014, because of changes in the course prompted by the previous year’s survey and student feedback. In the fall of 2014, the survey consisted of the following 10 questions, with the last question being open ended:

1. Did the IQ session with the drawing of the nephron help you learn the anatomy of the nephron?
2. Did the IQ session with the drawing of the nephron help you learn the physiology of the nephron?
3. Did the IQ session with the drawing of the nephron help you learn the function of the diuretics in the nephron?
4. Did you think the drawing of the nephron helped you increase your competence in renal function?
5. Did you continue to use the drawing of the nephron in subsequent renal IQ sessions?
6. Was working on the drawing of the nephron in a group helpful?
7. Would it have been better to have a facilitator present during the sessions?
8. Was Project Nephron a useful exercise?
9. Would you recommend Project Nephron for next year’s class?
10. Do you have any comments or suggestions for improvement?

In the first nine questions, the students were asked to determine whether they agreed or disagreed with the statement by circling a “yes” or a “no.” Adjacent to the “yes” or “no” line was a Likert type-scale asking the students to rate the degree of usefulness of each topic. The scale ranged from 1 to 5, with 1 being the lowest value and 5 being the highest value. On the survey, the first nine questions would appear as follows (using question 1 as an example):

1. Did the IQ session with the drawing of the nephron help you learn the anatomy of the nephron?

Yes No degree of helpfulness 1 2 3 4 5 (1 – low and 5 – high)

Table 1. Number of students who took the renal examination and the number of survey responses

|          | Fall 2014 | Fall 2015 |
|----------|-----------|-----------|
| Class size, $n$ | 65        | 64        |
| Surveys returned | 63        | 61        |
| %         | 97        | 95        |
| Surveys with questions answered | 19        | 56        |
| %         | 29        | 87        |
| Surveys with comments | 21        | 58        |
| %         | 33        | 91        |
| Survey without comments, no. | 42        | 3         |

Values show the no. and percentage of responses. $n$, No. of students.

Table 2. Entering number of students in each class and their MCAT scores

| Class Year | Entering Students, n | Mean MCAT Score | MCAT SD | MCAT High Score | MCAT Low Score |
|------------|----------------------|-----------------|---------|-----------------|----------------|
| 2015       | 64                   | 31              | 2.73    | 38              | 26             |
| 2016       | 63                   | 31              | 3.62    | 39              | 25             |
| 2017       | 63                   | 30              | 2.98    | 36              | 24             |
| 2018       | 64                   | 32              | 3.20    | 39              | 22             |

$n$, No. of students. MCAT, Medical College Admission Test; SD, standard deviation.

Question 10 was an open-ended question designed to have the students give their own knowledge or feelings about the project.

In the fall 2015, the survey contained the original 10 questions, and another 6 were added. That change increased the total number of open-ended questions to three. Only the first nine questions from the original survey were used for statistical comparison. Table 1 shows the number of students in the class who took the exam, the percentage of questionnaires returned, and the number of questionnaires that contained comments. Although the number of surveys returned is quite high for the fall 2014, unfortunately many participants did not answer the questions. For example, in question 1 for fall 2014 only 19 students out of 63 surveys checked the “yes” or “no” box which is only a 30% response. This lack of response continued throughout the remaining questions. In contrast, on question 1 for fall 2015, 56 students out of 61 surveys checked the “yes” or “no” box, which is a 91% response. This percentage of respondents continued for the rest of the fall 2015 survey.

RESULTS

Student Demographics

The demographics of the sophomores from 2012 through 2015 showed the majority had just finished college when they enrolled at CESCOM, making them around 21 or 22 yr of age. There were a few slightly older students in each class who had some life experiences, such as military service or previous work experience. Table 2 show the number of students in each entering class and their Medical College Admission Test scores. Table 3 shows the number of students who took the renal examination in each class and the distribution between men and women. There was no significant difference in the number of men and women in the classes across all 4 yr [$\chi^2$ (3) = 4.65, $P = 0.199$, and Cramer’s $V = 0.137$].

Academic Results

The academic results were measured by comparing the renal examination results of the fall 2012 and 2013 students to those

Table 3. Number of men and women taking the renal examination per class

| Fall Semester | Class Year | Men | Women | Total |
|---------------|------------|-----|-------|-------|
| 2012          | 2015       | 32  | 31    | 63    |
| 2013          | 2016       | 26  | 35    | 61    |
| 2014          | 2017       | 28  | 37    | 65    |
| 2015          | 2018       | 36  | 28    | 64    |

Values are $n$, no. of students.
of the students from the fall of 2014 and 2015 who used Project Nephron. Table 4 compares the average scores of each class on the renal examination. To assess the overall impact of Project Nephron on the nephrology learning objectives, one-way ANOVAs were conducted that investigated changes in test scores from the 2 yr before the project to the 2 yr using the project. As can be seen in Table 4, there were significant differences between 2012 through 2015 on the overall total test score \( F(3,269) = 6.3, P < 0.001, \) partial \( \eta^2 = 0.066 \). The highest test score occurred in the second year of Project Nephron with an average score of 90.2. This score was statistically higher from each other year, including 2012, where the students had the second highest average of 89.3 \( (P = 0.021) \). The 2015 total test score of 90.2 was a substantial improvement from the first year of the project (2014) in which students had an average test score of 86.0 \( (P < 0.001) \). This improvement might reflect changes that occurred during the second year of Project Nephron, when the students suggested eliminating the channels and transporter pathways from the drawing (Fig. 2). By the end of Project Nephron, there were also statistically significant improvements in renal histology and system pathology \( (P = 0.005 \) and \( P < 0.001 \), respectively). The only area that indicated a decrease in the mastery of knowledge was on the topic of acid-base and/or electrolytes, where the students in 2012 did significantly better than any other year \( (P < 0.001) \). However, students in 2015 scored significantly higher than those in 2013 and 2014 \( (P < 0.001) \) on the topic of acid-base and electrolytes. There were no significant differences across the years on pharmacology \( F(3,269) = 2.4, P = 0.062, \) partial \( \eta^2 = 0.027 \) and physiology \( F(3,269) = 2.3, P = 0.074, \) partial \( \eta^2 = 0.025 \).

**Survey**

**Quantitative results.** In 2014 and 2015, Project Nephron student surveys were collected to assess the student’s perceived value of the project and to provide formative feedback to enhance the fall 2015 class experience. In addition to the open-ended responses, nine items were consistent across the 2014 and 2015 surveys. As can be seen in Table 5, independent samples \( t \)-test was conducted to compare these items across the sophomore fall classes of 2014 to 2015. The survey was scored on a five-point Likert scale with 1 = low and 5 = high. This survey provided evidence that supported continued use of this project with an initial average overall score for 2014 of 3.7 out of 5.0. The modifications to Project Nephron that resulted from the 2014 survey showed statistically significant improvements in students’ perceived value in five of the nine areas addressed in the survey. The first area of improvement was that these changes increased the perceived value in helping students learn the nephron physiology, with scores improving from a 3.5 in 2014 to a 4.3 in 2015 \( [t(122) = -4.2, P < 0.001, \) Cohen’s \( d = -0.76] \). There were similar improvements in the topics of learning functions of diuretics \( [t(122) = -2.9, P = 0.005, \) Cohen’s \( d = -0.52], \) increase your competency \( [t(122) = -2.5, P = 0.015, \) Cohen’s \( d = -0.45], \) did it help working in groups \( [t(122) = -2.8, P = 0.006, \) Cohen’s \( d = -0.51], \) and would you recommend this project for next year’s class \( [t(122) = -2.1, P = 0.034, \) Cohen’s \( d = -0.39]? The overall average across all of the nine items indicated a statistically significant improvement in the perceived value of Project Nephron within the average score increasing from 3.7 to 4.1 \( [t(122) = -3.3, P = 0.001, \) Cohen’s \( d = -0.60].

**Table 4. One-way ANOVA of average student scores on the customized examination from the National Board of Medical Examiners from 2012 to 2015**

| Tests                    | 2012 \( n = 63 \) | 2013 \( n = 61 \) | 2014 \( n = 65 \) | 2015 \( n = 64 \) | \( F \)-Test | \( P \) Value | Partial \( \eta^2 \) |
|-------------------------|------------------|------------------|------------------|------------------|-----------|--------------|------------------|
| Total test              | 89.3             | 88.4             | 86.0             | 90.2             | 6.3       | <0.001*      | 0.066            |
| 1. Acid-base and/or electrolytes | 86.1            | 79.6             | 75.7             | 82.3             | 14.7      | <0.001*      | 0.087            |
| 2. Renal histology      | 86.5             | 88.5             | 85.7             | 90.9             | 10.5      | 0.005*       | 0.046            |
| 3. Pharmacology         | 94.8             | 91.9             | 90.9             | 93.4             | 10.7      | 0.062        | 0.027            |
| 4. Physiology           | 89.9             | 90.2             | 86.8             | 89.1             | 9.2       | 0.074        | 0.025            |
| 5. System pathology     | 91.6             | 90.5             | 87.2             | 92.5             | 8.5       | 0.001*       | 0.075            |

Values are means and SDs; \( n \), no. of students. *All means are statistically significantly different from each other.

**Table 5. Independent \( t \)-test comparing responses to the medical student survey for class of 2014 and 2015**

| Items                                      | Fall 2014 \( n = 63 \) | Fall 2015 \( n = 61 \) | \( t \)-Test | \( P \) Value | Cohen’s \( d \) |
|--------------------------------------------|------------------------|------------------------|--------------|--------------|---------------|
| Did the drawing help learn nephron anatomy | 4.0                    | 4.2                    | -1.4         | 0.152        | -0.26         |
| Did the drawing help learn nephron physiology† | 3.5                    | 4.3                    | -4.2         | <0.001*      | -0.76         |
| Improve learning functions of diuretics†    | 3.7                    | 4.3                    | -2.9         | 0.005        | -0.52         |
| Increase your competency†                  | 3.8                    | 4.3                    | -2.5         | 0.015        | -0.45         |
| Continue use of drawing in other renal IQ sessions | 4.3            | 4.2                    | 0.7          | 0.504        | 0.12          |
| Did it help working in groups†             | 3.2                    | 3.9                    | -2.8         | 0.006        | -0.51         |
| Would a facilitator present make it better | 2.1                    | 2.5                    | -1.6         | 0.123        | -0.28         |
| Was project nephron a useful exercise       | 4.1                    | 4.5                    | -1.9         | 0.061        | -0.34         |
| Would you recommend the project for next year* | 4.3                    | 4.7                    | -2.1         | 0.034        | -0.39         |
| Total Score†                               | 33.6                   | 36.7                   | -3.3         | 0.001        | -0.60         |
| Average Score†                             | 3.7                    | 4.1                    | -3.3         | 0.001        | -0.60         |

Note: bold indicates statistical significance: *\( P < 0.05 \) and †\( P < 0.01 \).
Qualitative results. OPEN-ENDED STUDENT FEEDBACK: FALL 2014. The student comments from the open-ended questions were categorized as to what the students found useful about Project Nephron and how it could be improved. The comments from the fall of 2014 indicated the project was useful because it forced the students to learn about the nephron at the beginning of the course rather than having them wait until later; it gave them an overview of the nephron before the lectures; and the drawing was a useful reference for the subsequent renal IQ cases. The students thought the project could be improved by removing the pathways showing the channels and transporters of the cells (Fig. 1). This suggestion was adopted, and the pathways were removed from the fall 2015 drawing (Fig. 2). Other suggestions included renal physiology lectures before receiving the drawing (the lectures were concurrent), the drawing should be done at the end of the course, and the drawing should be done in the context of a clinical case.

OPEN-ENDED STUDENT FEEDBACK: FALL 2015. The student comments were again categorized into what was useful about Project Nephron to the students and how it could be improved. The project was useful, because it gave them an immediate understanding of the nephron, and it made learning the subsequent histology and physiology easier. It forced them to learn the nephron physiology at the beginning of the renal block, rather than allowing them to procrastinate until the end of the course. The drawing was posted in the small-group classrooms and was a useful reference for the subsequent renal clinical cases.

DISCUSSION

Academic Results

The objective of this study was to investigate the value of Project Nephron in improving the ability of the sophomore medical students to master renal histology, physiology, and pharmacology. If it helped, one would expect to see an increase in the overall test scores for the years 2014 and 2015 over the years 2012 and 2013 when it was not used. One would expect to see specific improvements in the areas of histology, physiology, and pharmacology, which were the three main areas addressed by the drawing. The drawing would not be expected to improve the grades in the areas of electrolytes and acid-base balance or system pathology.

In the second year of the project (2015), the total test score of 90.2 was an improvement from the first year of the project (2014) in which students had an average test score of 86.0 and was statistically significantly different (Table 4). This increase of the score may have been due to a change in the drawing where the tubular epithelial cells were left in, but the locations of the channel and transporter pathways were removed. This change may have caused the fall 2015 students to be more focused on finding and describing the pathways than the students from 2014. In the areas of histology, physiology, and pharmacology, there was only a statistically significant difference in the histology test score for the 2015 students with a score of 90.9 compared with a score of 85.7 for the 2014 students (Table 4). No specific factor can be identified to account for this improvement. In the areas of pharmacology and physiology, there were no statistically significant differences in the grades. In pharmacology, total test scores ranged from a low of 90.9 to a high of 94.8, with an average of the mean test score being 92.75. The students in 2012 and 2013 kept a pharmacology log with a list of all of the renal medications and their mechanisms of action. One would expect these students to do better in the pharmacology area, but they scored about the same as the students from 2014 and 2015 (Table 4). In physiology, the test scores ranged from a low of 86.8 to a high of 90.2, and the average of the mean test scores was 89. The student test scores show they have mastered these two areas very well with slight room for improvement. The consistently high grades in pharmacology and physiology are not the result of Project Nephron.

The fall 2015 system pathology grade showed a statistically significant difference over the previous 3 yr, but the improvement cannot be attributed to the use of the drawing. The drawing did not focus on histopathology. The drawing may have aided the students, in the sense that, once they acquired a fundamental knowledge of renal histology, it was easier for them to identify pathological changes. Review of the course schedule showed that the pathology lectures covered the same material for all 4 yr, and the virtual microscopy pathology laboratory was the same for all 3 yr. There were no changes in the lectures or the pathology laboratory that would account for the improved score.

Project Nephron was not aimed at improving the test score in the area of acid-base and electrolyte balance. The students from 2012 did the best on that section with a score of 86.1 (Table 4). The scores in this area ranged from 75.7 to 86.1, and the average of the mean test score was 80.9 with a standard deviation of 4.38. This mean test score of 80.9 is about 8–10 points lower than that of the other four tested areas. The mean test scores for the other areas ranged from a low of 87.9 (renal histology) to a high of 92.75 (pharmacology). Review of the academic schedule for all 4 yr showed the instructional time devoted to acid-base and electrolyte balance was about the same for each year. The lower grades in this area were an unexpected finding of the study. The reason for the lower scores over all 4 yr is not clear. Possible explanations include the following: 1) lack of emphasis by the faculty; 2) not enough lectures; and 3) not enough group practice in doing acid-base and/or electrolyte balance problems.

Survey Results

Quantitative results. The students received the questionnaire a few days before the end of the course. The student survey from both years thought Project Nephron was beneficial. Table 5 compares the responses from the students in the fall of 2014 to those of the fall of 2015 over the nine items in the survey. The statistical analysis shows an increase in perceived value in Project Nephron from 2014 to 2015. The students of 2015 saw an increase in perceived value of five of the survey items from the previous group. These items included the following: was the drawing helpful in learning the nephron physiology, was it helpful in learning the function of diuretics, did it increase your competency, did it help working in groups, and would you recommend the Project Nephron for next year?

Qualitative results. The comments were reviewed and placed into one of two categories: 1) what was useful about Project Nephron; and 2) what could be improved in Project Nephron? The usefulness of the project to the students can be summarized as follows:
Using the drawing at the start of the course was helpful, because it gave the students an immediate framework for understanding the histology, pharmacology, and physiology of the nephron. 

Project Nephron did not allow the students to put off learning renal physiology until later. 

The drawing was posted and was always present in the IQ rooms; it served as a reference and became more useful as the course went on.

The most important benefit of the project was that it gave the students an immediate understanding of the nephron’s function. 

The student-suggested improvements to Project Nephron can be summarized as follows:

- The transporter and channel pathways for the 2014 Project Nephron should be deleted and just the cells be put in the drawing (adopted for the 2015 Project Nephron drawing). 
- There should be more renal physiology before doing the project, and it should be put in the context of an IQ case. 

The first improvement was incorporated into the 2015 Project Nephron. The other suggestion is difficult to implement, because of the course time constraints.

Faculty Input

Faculty facilitators, who were in the small-group learning rooms while the students were discussing the clinical renal IQ cases, reported that the students would frequently refer back to the nephron drawing. They would use the drawing to explain the physiology to the other students.

Conclusions

In summary, Project Nephron contributed to improving the overall test scores of the students in the fall of 2015, as well as in the area of renal histology. It did not improve the scores in the areas of renal physiology and pharmacology, which were already high. An unexpected finding of the study was that the average examination scores in each year for the acid-base and electrolyte balance area were consistently 8–10 points lower than the scores in the other four areas. The reason for these consistently lower scores is not apparent. This finding suggests there may be a problem in the curriculum, such as 1) lack of emphasis by the faculty; 2) not enough lectures in the area; 3) not enough practice of doing acid-base and/or electrolyte balance problems. The survey shows that the students liked the drawing and that the completed drawing served as a useful reference for the remaining clinical IQ cases. The drawing would be most helpful in the setting of small self-directed learning groups, which use clinical cases. Introducing it before starting the clinical cases gives the students a foundation of nephron physiology, histology, and pharmacology on which they can discuss their cases. The renal course is 4 wk long, and this is a short period of time for the students to learn both renal physiology and pathophysiology. In a medical school setting where most or the entire curriculum is delivered by lecture, the drawing might not be as useful. The strength of the small class groups is the interaction between the students, which results in active learning and makes Project Nephron a potentially useful tool in medical education.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

P.G.R. conceived and designed research; P.G.R. and D.N. analyzed data; P.G.R., D.N., L.Z.V., and D.K.B. interpreted results of experiments; P.G.R., C.L.R., L.Z.V., D.K.B., and M.H.L. drafted manuscript; P.G.R., D.N., C.L.R., L.Z.V., D.K.B., and M.H.L. edited and revised manuscript; P.G.R., D.N., C.L.R., L.Z.V., D.K.B., and M.H.L. approved final version of manuscript; C.L.R. prepared figures.

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