RENAL TRANSPORT IS A CENTRAL MECHANISM underlying electrolyte homeostasis, acid-base balance, and other essential functions of the kidneys in human physiology. Thus, knowledge of the anatomy and physiology of the nephron is essential for the understanding of kidney function in health and disease. However, students find this content difficult to comprehend and retain for a number of reasons, including the amount of detailed information regarding the location of transporters throughout the varying regions of the nephron, the location within the membranes (apical vs. basal) of the epithelial cells lining the tubules, the directionality of solute transport resulting in secretion or reabsorption, hormone regulation, and drug targeting. Much of this material lends itself to rote memorization for learning.

Incorporation of active learning activities in conjunction with more traditional approaches to teaching in the classroom have proven to be more effective for student learning and retention compared with lecture alone (2, 4-7, 10). Active learning methods promote higher-order objectives on Bloom’s taxonomy, such as analysis, synthesis, and evaluation (1, 8). Therefore, this article introduces an active learning exercise with the objectives of facilitating the learning of 1) nephron anatomy, 2) transporter secretion and reabsorptive functions, 3) regulation of transporter activity by hormones, 4) the mechanism of action of various therapeutic drugs that target renal transporters directly or indirectly, and 5) the applicability of the content to “real world” clinical scenarios.

Description of the active learning exercise. The active learning exercise consisted of two parts: constructing a diagram of a nephron and using the diagram to assist in answering think-pair-share questions. After completion of a lecture, in which electronic notes were provided to students in advance, students were asked to construct a figure of a nephron, an assignment that was to be completed outside of class. The lecture notes and the lecturer presented the information in sections based on the different functional regions of the nephron (proximal convoluted tubule, thin descending loop of Henle, thick ascending loop of Henle/early distal convoluted tubule, and late distal convoluted tubule/collecting ducts) and included transporter location, directionality of solute transport, and hormone regulation. Students were directed to include in their diagram all of the transporters that were discussed in class that were placed in the appropriate location and orientation within the nephron. Students were also directed to label the actions of aldosterone, angiotensin II, antidiuretic hormone, and parathyroid hormone as well as a variety of therapeutic drugs (carbonic anhydrase inhibitors, loop diuretics/furosemide, thiazide, and spironolactone) on the diagram. The mechanism of action of the drugs was not included in the lecture notes nor discussed during lecture; the students were responsible for researching this information independently using reputable resources. The purpose of constructing the diagram was to facilitate the critical evaluation required to piece together all of the presented information into a complete nephron. In the end, the diagram would allow the students to have an image of a single nephron in their minds, with all of the relevant information integrated, instead of a fragmented understanding as it was presented in the notes and during lecture.

It was recommended that students hand-draw their diagram rather than computer-generate the figure by cutting and pasting from the lecture notes. By hand-drawing, the brain is actively engaged in analyzing the orientation and proper placement of the transporters within the nephron and tubule cells compared with simply cutting and pasting. Although computer use in the classroom is becoming ever more popular, current literature supports that traditional hand-writing of notes may be more effective for learning and memory than computer typing of notes (9). It was the intent of the assignment to engage the brain to critically evaluate each transporter to facilitate a deeper learning. Thus, the primary goal of the exercise was not necessarily the final product but engagement in the process.

In addition to drawing a nephron, a second component of the active learning exercise included using the figure to assist in answering think-pair-share style questions, an in-class activity. Think-pair-share is a strategy where small groups or pairs of students work together to solve a problem or answer a question. Students first think independently to answer a question before sharing their thought process with others in the group. The think-pair-share strategy increases communications that are necessary to internally process, organize, and retain ideas (11). Many of the questions were geared toward the effects of angiotensin II, aldosterone, and therapeutic drugs on electrolyte and acid-base homeostasis. Questions included the following:

1. What effect do loop diuretics and thiazides have on potassium homeostasis?
2. What are two mechanisms of how loop diuretics and thiazides can cause hypokalemia?
3. What acid-base disorder can be caused by loop diuretics and thiazides?
4. What effect can spironolactone have on potassium homeostasis?
5. What acid-base disorder can be caused by spironolactone and by which mechanism(s)?
6. If angiotensin II increases glomerular filtration rate, how does it play a role in increasing blood volume?
Illuminations

7. What acid-base disorder can be caused by extracellular fluid volume contraction and by which mechanism(s)?
8. Can hyperaldosteronism cause hypochloremia or hyperchloremia?
9. What acid-base disorder can be caused by carbonic anhydrase inhibitors and by which mechanism(s)?
10. What effect can ace inhibitors have on potassium balance and by which mechanism(s)?
11. What effect can loop diuretics have on magnesium homeostasis and by which mechanism(s)?

The answers to the think-pair-share questions were discussed in class. The purpose of this component of the exercise was to critically analyze the effects of the hormones and select therapeutic drugs on the body via direct or indirect action on renal transporters and to also critically evaluate the location and directionality of solute transport leading to secretion or reabsorption, which was necessary to correctly answer the questions. The think-pair-share quiz was also intended to enhance awareness for the clinical applicability of the course content.

**Student perceptions of the active learning exercise.** To determine student perceptions of the active learning exercise, a survey was given to 103 first-year professional degree pharmacy students enrolled in a Biological Sciences Integrated course (3) during the spring semester of 2016. The response rate of the survey was 76.7%. However, 14 of the 79 students who completed the survey did not partake in drawing a renal diagram; they participated only in the think-pair-share questions. Table 1 includes the responses to survey questions from only those students who completed a renal diagram and participated in the think-pair-share questions (65 students). The results of the survey suggest that the activity improved understanding of the nephron anatomy and physiology regarding transporter location, directionality of solute transport, and regulation by hormones. In addition to students believing that the activity improved their understanding of the course material, the majority of students believed that the activity reinforced their appreciation for the importance of the subject matter, enhanced their desire to learn the subject matter, and improved their approach for studying the content for the course exam.

Since the activity was two-pronged, students were asked which component was more impactful for their learning; 40.0, 21.5, and 38.5% chose constructing the diagram, the in-class think-pair-share quiz, or both, respectively, as equally as important.

The survey also revealed that students are more motivated to study a concept or subject matter outside of class if they understand it during class compared with if they do not understand it during class. Since students felt that the activity increased their understanding of renal transporters, it is possible that the activity had an extended effect of increasing the desire to study renal transporters outside of class for the course exam.

Students were asked for possible explanations if they did not find the activity beneficial for their learning. Several students commented that they were not sure how or where to draw the transporters and were concerned that they did not know whether their diagram was drawn correctly; they would have preferred that the professor had gone over the drawing in class so that they knew their diagram was drawn correctly. It was the intent of the activity that the students critically compare their own drawing with those in the lecture notes to the point that they felt confident that it was correct. The process of critical evaluation was intended to be a central component of the activity. More emphasis on the intent of this portion of the activity by the professor may be helpful for future implementation of the activity. Furthermore, to ease student anxiety, the professor can choose to provide a means of comparing their diagram to a complete and accurate diagram.

**Suggestions for implementation of the active learning exercise.** To improve engagement in the activity by more students, it is suggested that a formal or informal assessment be coupled to the assignment. For example, it can be required as a part of the formal assessment of the course, or extra credit can be awarded for the assignment. During the first few semesters of implementing this activity in class, the students were told that they would be given extra credit points if they completed a diagram and scored 100% on the think-pair-share quiz. Although the extra credit was only ~2 points out of 650 total course points, students were still incentivized; the majority of the class engaged in both components of the activity.

### Table 1. Student perception survey

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The activity as a whole (constructing the diagram and quiz) improved my understanding of nephron function.</td>
<td>38.5% (25)</td>
<td>49.2% (32)</td>
<td>12.3% (8)</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>The activity as a whole improved my understanding of hormone effects on tubular transport.</td>
<td>35.4% (23)</td>
<td>46.2% (30)</td>
<td>15.4% (10)</td>
<td>3.1% (2)</td>
<td>0%</td>
</tr>
<tr>
<td>The activity improved my understanding of the nephron anatomy regarding transporter location and directionality of solute transport.</td>
<td>43.1% (28)</td>
<td>47.7% (31)</td>
<td>9.3% (6)</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>The activity reinforced or enhanced my appreciation for the importance of understanding the course content.</td>
<td>27.7% (18)</td>
<td>56.9% (37)</td>
<td>10.8% (7)</td>
<td>4.6% (3)</td>
<td>0%</td>
</tr>
<tr>
<td>The activity enhanced my desire to learn the course content.</td>
<td>26.2% (17)</td>
<td>36.9% (24)</td>
<td>32.3% (21)</td>
<td>4.6% (3)</td>
<td>0%</td>
</tr>
<tr>
<td>The exercise helped to improve my approach for studying the content for the course exam.</td>
<td>33.9% (22)</td>
<td>43.1% (28)</td>
<td>18.5% (12)</td>
<td>1.5% (1)</td>
<td>3.1% (2)</td>
</tr>
<tr>
<td>I enjoyed the activity as a whole compared with lecture alone.</td>
<td>32.3% (21)</td>
<td>46.2% (30)</td>
<td>16.9% (11)</td>
<td>3.1% (2)</td>
<td>1.5% (1)</td>
</tr>
<tr>
<td>I am more likely to want to study course material outside of class the more I understand it during class (compared with material that I did not understand during class).</td>
<td>58.5% (38)</td>
<td>27.7% (18)</td>
<td>6.2% (4)</td>
<td>6.2% (4)</td>
<td>1.5% (1)</td>
</tr>
</tbody>
</table>

Nos. in parentheses are the number of students who answered.
Most recently, the activity was implemented with no extra credit or formal assessment, which resulted in a drop of student engagement from ~90 to 70%. Furthermore, it is possible that without the extra credit incentive for scoring 100% on the think-pair-share quiz, that students did not approach the questions with the same level of commitment and critical analysis. Thus, to maximize student engagement, it is suggested that a formal or informal assessment be assigned to the activity.

Instructors can adapt the activity to include additional hormones or therapeutic drugs and customize the think-pair-share questions to match the learning outcomes of the course.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS

A.J.D.-N. conception and design of research; A.J.D.-N. performed experiments; A.J.D.-N. analyzed data; A.J.D.-N. interpreted results of experiments; A.J.D.-N. drafted manuscript; A.J.D.-N. edited and revised manuscript; A.J.D.-N. approved final version of manuscript.

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