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Mapping the Nephron Exercise Incorporates Multiple Learning Strategies

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Appendices

A. Facilitators Guide.docx
B. Student Handout.pptx
C. Expectations for Student Work.pdf
D. Concept Check Questions .pptx
E. Student Evaluation Survey .docx

All appendices are peer reviewed as integral parts of the Original Publication.

Abstract

Introduction: Understanding the location and action of nephron transporters and channels is important to the understanding of renal function. As each region of the nephron is unique in its inclusion of specific transporters and channels, mapping of the nephron is an effective first step in understanding overall nephron processing. We describe a small-group, active-learning exercise that facilitates students' ability to understand renal processing within each region of the nephron. **Methods:** Following an overview lecture on renal transporters and channels, small groups of students worked cooperatively to map the nephron. This 2-hour, collaborative exercise was developed to reinforce key concepts in renal processing of ions and nutrients and, at the same time, utilize effective learning strategies. Learning strategies incorporated in this exercise include small-group collaboration, peer teaching, retrieval practice using an audience response system, and elaboration through discussion. **Results:** Written examination was used to assess student understanding. Students demonstrated higher performance on a subset of questions related to this learning activity compared to the overall exam. Highly positive feedback was provided by a convenience sample of students completing an anonymous survey. **Discussion:** This nephron-mapping exercise was an effective means to promote synthesis and analysis of lecture content and engage students in methods that enhance learning.

Keywords

Active Learning, Hormones, Diuretics, Nephrology, Renal, Peer Teaching, Collaborative Learning, Nephron, Retrieval Practice

Educational Objectives

By the end of this small-group exercise, learners will be able to:

1. Describe, in the juxtamedullary nephron, mechanisms involved in processing of Na^+, Cl^-, Ca^{2+}, HCO_3^-, phosphate, glucose, amino acids, and water.
2. Describe the general role of each region of the renal tubule (proximal convoluted tubule, proximal straight tubule, descending thin limb of loop of Henle, ascending thin limb of loop of Henle, thick ascending limb of loop of Henle, distal convoluted tubule, connecting tubule, cortical collecting duct, and outer and inner medullary collecting duct).
3. Discuss the impact of angiotensin II, aldosterone, antidiuretic hormone, and parathyroid hormone on nephron processing.
4. Contrast and compare the effects of the following diuretics on nephron processing: carbonic anhydrase inhibitors (acetazolamide), osmotic diuretics (mannitol), loop diuretics (furosemide), thiazide (hydrochlorothiazide, bendroflumethiazide, chlortalidone), and potassium sparing (amiloride, spironolactone).

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In 2002, the Association of American Medical Colleges established the Institute for Improvement in Medical Education with a primary goal of supporting reform efforts to engage students in more active and integrative learning.[1,2] Although difficult to define precisely, active learning is generally considered to be the process of engaging students in activities that require them to participate or contribute to attainment of knowledge; active learning shifts the responsibility for learning from the teacher to the student.[3] Reform efforts have promoted active learning as a means to improve student engagement and development of skills such as writing, evaluating, synthesizing, analyzing, and thinking critically. Although active learning, also termed nondidactic, is not defined precisely, it generally includes any classroom methodology that is not a faculty-focused lecture.

Researchers have found that small-group, active-learning exercises are effective in achieving desired outcomes.[4-7] Students also report that they are comfortable expressing confusion and asking questions when working in groups with other individuals who have similar backgrounds and experience.[8] Small-group, interactive exercises may be especially useful when introducing students to materials they traditionally find exceptionally challenging, such as renal physiology. An editorial sharing the experiences of medical students indicated that students often perceived nephrology as overly complicated and that this negatively impacted attitudes: The students reported that nephrology is rich in concepts and skills that are difficult to comprehend, and this often leads to discouragement and a low level of interest in the field.[9] Because of the well-documented decline in the number of medical school graduates pursuing fellowships in nephrology, there is a need to develop and deliver enjoyable, engaging, and effective learning experiences early in students' academic careers. Furthermore, it is essential that faculty evaluate new and innovative approaches to ascertain student attitudes and provide evidence of effectiveness.[6,10]

This resource was developed for first-year medical students as an active-learning exercise for a Fundamentals of Health and Disease (FHD) course. This course is considered introductory, as more extensive renal physiology is covered in a renal course for second-year medical students. The course was scheduled with 2-hour lectures, followed by 2-hour blocks of active learning. By design, active-learning exercises required students to work cooperatively in small groups and to apply higher-order skills such as analysis, synthesis, and application. The renal unit within FHD consisted of 6 hours of lecture and 6 hours of small-group activity.

One particularly effective example of an FHD small-group exercise was mapping the nephron. This exercise followed a 2-hour lecture block that delivered content focused on renal processing of multiple nutrients and ions. This lecture included the location and function of nephron channels and transporters, delivered in sequence as they pertained first to sodium (and chloride), followed by potassium, calcium, phosphate, and magnesium. The action of a select few hormones and diuretics was also briefly discussed. This exercise preceded coverage of more complex mechanisms of water and salt regulation and acid-base balance.

The primary objectives of this nephron-mapping exercise were to ensure students acquired a working knowledge of nephron processes essential to future lectures and to engage students in effective learning strategies. The exercise included the following three key components:

- Collaborative efforts of small groups to generate illustrations mapping the nephron.
- Peer learning/reciprocal peer teaching.
- Formative quiz using an audience response system (clickers).

Although this exercise did not fit the strict definition of concept mapping (i.e., use a series of circles and arrows to describe relationships among concepts), it did provide a template (diagram of the nephron) to help organize and structure knowledge.[11] In the exercise, students described juxtamedullary nephron processing in each of the defined regions of the tubular system.[12] Within each region, students were asked to indicate the presence of transporters and channels responsible for processing (reabsorption and secretion) nutrients, ions, and water as discussed in the prior lecture. The exercise provided an opportunity for students to integrate, analyze, and synthesize foundational information from the lecture (and textbook) and at the same time practice a number of effective learning strategies.

Although others have published active-learning exercises that address renal concepts, such offerings are typically case-based and often clinical in nature.[13,14] Effective implementation of a case-based (or any type of problem-based) learning exercise requires learners to have previously mastered important fundamental concepts. Considering that a course in physiology is not required for acceptance at our medical school, first-year medical students are often experiencing nephrology for the very first time. To our knowledge, there are no previously published active-learning exercises aiming to develop mastery of foundational concepts for first-year medical students. The current exercise uses a visual organizer to assist the learner in preparing for more advanced and clinically oriented learning experiences. The exercise provides students with the opportunity to work cooperatively in small groups and to build a product as they review lecture notes and map the nephron. This exercise requires elaboration and discussion, both of which have been demonstrated to foster conceptual understanding.[15,16] Evidence in the literature indicates that group discussion aids in retention, promotes reorganization, increases awareness of erroneous reasoning, and assists students in identifying gaps in personal knowledge.[17,18] Based upon student evaluation and exam performance, this nephron-mapping exercise met its objectives as it engaged students in synthesizing, evaluating, and applying information critical to foundational understanding of basic renal processes.

Methods

This small-group activity was distributed for use in an introductory basic science course involving all first-year medical students at a large medical school. This active-learning exercise followed a 2-hour didactic lecture covering the mechanisms of sodium, potassium, calcium, phosphate, and magnesium handling by the kidney, as well as an introduction to hormones and diuretics impacting renal function. Lecture content, derived from *Vander's Renal Physiology,*[19] was considered introductory as students would complete an additional systems-based course focused on renal physiology in the second year of medical school.

One month prior to the scheduled delivery of this activity, an instructor's guide was distributed along with each of the documents listed below. All faculty leading the exercise were either PhD or MD faculty who also delivered the corresponding renal lecture.

Resource files included in this submission as appendices are described below.

- Facilitators Guide (Appendix A).
- Student Handout (Appendix B): instructions and illustration of the nephron to be distributed to all students at the beginning of the class period.
- Expectations for Student Work (Appendix C): labeled nephron and summary tables.
- Concept Check Questions (Appendix D): PowerPoint slides of multiple-choice questions with animated solutions and rationale. Use of a student response system such as Turning Technology, Poll Anywhere, or Top Hat is recommended.
- Student Evaluation Survey (Appendix E).

A sample schedule for the module is presented below.

- 0-40 minutes: mapping the nephron illustration—small groups working independently.
- 40-60 minutes: preparing for reciprocal peer teaching—small groups working independently.
- 60-90 minutes: reciprocal peer teaching—class convened in one location; groups present/teach one at a time.
- 90-120 minutes: formative assessment (clicker questions)—class convened in one location; use of student response system.

To begin the class, students were divided into small groups of three to five students per group. Small groups were then dispersed to meet, discuss, and complete the assigned activity. Student groups were given 40 minutes to map the location and function of juxtamedullary nephron channels and transporters covered in the prior lecture. Although students worked collaboratively, each student was given a copy of the instructions and nephron illustration to map. A sample of completed student work is provided in Appendix C. The formatted tables included with the illustrations in Appendix C were generated by students who summated concepts covered following completion of the activity. These tables could be used by faculty as a key.

After the 40-minute work period, student groups returned to the classroom. As groups returned, they were instructed to prepare to teach one of the following five categories: proximal tubule (convoluted and straight tubule), loop of Henle (descending and ascending, including thick ascending limb), distal tubule and collecting ducts, hormones, and diuretics. Although not all groups got to teach, all prepared to do so.

Each group was then given an additional 20 minutes to summarize the general activity of each region, the hormone, or the diuretic. Each group was also charged with naming one or two individuals who would present this information to the class. In our classroom, groups were given large sheets of butcher-block paper (taped to the wall) to illustrate their assignments. Alternatively, students could be asked to use chalkboards, whiteboards, or digital images that could be projected.

During the final 30 minutes of the class, an audience response system was utilized to further promote student interaction and gauge comprehension of the material. Turning Technology software was used to prepare a set of 10 questions to be projected on a large screen at the front of the classroom. Students were given 1-3 minutes to answer each of the questions depending on the nature of the question and how quickly groups submitted their answers. The percentage of students choosing each response was made visible before students engaged in elaborating on possible rationales for each selection. Correct answers and the instructor's rationale were then shared with the group. Although individual student responses were not captured, this option is available and may be used by the instructor to evaluate individual student progress or even for grading purposes.

To conclude the session and guide the students into thinking about subsequent lectures in pathology and pharmacology, students were offered additional questions to ponder on their own:

- Hypothesize as to the effects of malfunction of renal transporters on homeostasis.
- Discuss how each of the hormones in excessive or inadequate amounts might affect body function.
- Consider what criteria a physician would consider when prescribing diuretics.

Students were also instructed to use a variety of resources in addition to their notes and textbook when studying. For further information and a recap of the lecture, students were referred to computerized modules (first published in MedEdPORTAL, now available online).[20]

Results

At the end of the 6-week block, an exam that included 23 renal questions was delivered. Nine of these questions required students to apply their understanding of concepts covered in the exercise and were therefore used to evaluate effectiveness of the exercise in promoting student understanding (Table 1). Only one question demonstrated an unacceptably low point biserial. Removing this question from consideration did not change our interpretation of results, and therefore, the question remains in Table 1.

Table 1. Performance on National Board of Medical Examiners Step 1 Exam Questions Related to Nephron Processing

		Item Difficulty		Point
Item	Concept	School	Step 1	Biserial
1	Diuretics	.67	.82	.40
2	Reabsorption/secretion	.71	.71	.28
3	Reabsorption/secretion	.79	.71	.47
4	Loop of Henle	.79	.71	.32
5	Collecting duct	.83	.85	.08[a]
6	Glomerular filtration	.89	.81	.35
7	Renal processing	.91	.80	.25
8	Renal processing	.95	.69	.37
9	Sodium reabsorption	.60	.78	.29
Average		.79	.76	

[a]When this low point biserial is eliminated, averages remain the same (.79 and .75).

An item difficulty index ranging from 0 (no student answered correctly) to 1 (all students answered correctly) evaluated student performance on each question. Thus, a difficulty index of .79 indicates that

79% of students answered the item correctly.[21] Although caution should be exercised when evaluating these results, the 356 first-year students completing these nine questions averaged 79% correct responses compared to 76% for National Board of Medical Examiners (NBME) universal results. These data indicate that although renal coverage for this course was considered introductory, students performed comparable to, or slightly better than, students previously completing this specific set of NBME questions.

A convenience sample of students was assembled to gather feedback following the exercise. Twenty-three students anonymously completed a short survey including three questions with Likert-scale responses and three open-ended questions (Table 2).

Table 2. Student Survey

Question	Average Score
1. This exercise effectively implemented the use of a visual organizer in understanding nephron processing.	3.61
2. This exercise enhanced my ability to organize, analyze, and elaborate on the roles of a variety of nephron transporters and channels.	3.70
3. This exercise enhanced my understanding of the impact of hormones and diuretic drugs on nephron processes.	3.70
4. What did you find most helpful in this exercise?	N/A
5. What did you find least helpful in this exercise?	N/A
6. What changes could the authors make to improve this exercise?	N/A

Questions 1-3 were scored on a 4-point Likert scale (1 = *strongly disagree,* 2 = *disagree,* 3 = *agree,* 4 = *strongly agree*). Questions 4-6 were open-ended.

Student survey responses indicated perceived usefulness of the exercise, with average Likert scores of 3.61 for question 1 and 3.70 for questions 2 and 3 on a 4-point scale. Responses to open-ended questions were also very positive. When asked "What did you find most helpful in this exercise?", many students expressed value in generating a visual guide that helped organize concepts. Others commented that discussion with peers helped them consolidate ideas and commit material to memory. One student wrote that the wrap-up afterwards was helpful because it served as a concise walk-through of the entire nephron. Student comments also provided excellent suggestions for improvement. Several students suggested including a word bank or list of all items to be considered to serve as a guide. In response to this suggestion, we have included tables in the samples of student work (Appendix C) that can be modified to the level of instruction and priorities of specific faculty. Students seemed pleased to have the integrated pharmacology and asked that additional drugs impacting renal function be included in the exercise. Although any number of additional drugs could be included, this course is considered introductory, and additional pharmacological agents are discussed in a renal systems–based course during the second year. Students also reported feeling rushed or needing more time to thoughtfully complete their visual organizer following peer instruction. As the time period is fixed at 2 hours, the only way to allow additional time would be to eliminate the clicker questions at the end of the exercise. It would be possible to either hand the questions out or post them to the course platform for utilization at a later time.

Discussion

As evidenced by student comments and performance on associated exam questions, this nephron-mapping exercise proved an effective way for students to visually organize information, analyze how location and function of specific transporters and channels contribute to nephron function, and contrast and compare the action of a variety of hormones and diuretics. Although this exercise was delivered during the first year of a medical curriculum, it is appropriate for use in teaching other graduate and professional students. With modification, it would be effective with undergraduate students.

Prior to curriculum reform, renal physiology was covered as a unit within a semester-long course that relied heavily on didactic instruction. Students enrolled in the prior curriculum had little opportunity for retrieval practice, peer collaboration, or formative assessment. Historically, the unit exam covering renal physiology demonstrated the lowest average of all three course exams. In the current semester, all course exams displayed similar averages. Direct comparison of exam question performance could not be made as prior renal exam questions were instructor written, not composed of NBME items. Therefore, a valid comparison of student learning, as assessed by differences in exam performance, was not possible.

During the nephron-mapping session, students worked collaboratively to build a product and engage in multiple forms of retrieval practice. First, they worked together to review lecture notes and summarize concepts by mapping an illustration of the nephron. This type of group interaction requires elaboration and discussion, which have been shown to foster conceptual understanding.[15,16] Others have demonstrated that group discussion aids in retention, stimulates reorganization, increases awareness of erroneous reasoning, and helps identify gaps in personal knowledge.[6,17,18] Collaborative group work has also been reported to be most effective when collaborators develop a product. Products, such as the mapped nephron, provide a group work space in which results of thinking become evident.[22]

A second approach used in this exercise was peer instruction. In a review published in 2007, Ten Cate and Durning[8] discussed many reasons for incorporating peer teaching in medical education. Specifically, they stated that near-peer teaching (where learners and teachers are similar in their level of knowledge) creates an environment where learners feel comfortable discussing concepts and expressing difficulties. In one study reporting on the use of peer teaching within a medical curriculum, 100% of students agreed that peer teaching increased their understanding of topics, and 97% believed this approach improved their retention of material.[23] These findings encourage more frequent inclusion of peer teaching in the medical education classroom.

To provide a means for students to further process and apply conceptual knowledge, the session wrapped up with a formative group quiz delivered using an audience response system. Others have consistently demonstrated that compared to student performance in classrooms not using student response systems, students who engage in clicker-based activities retain information longer and perform better on examinations.[4,24,25] Retrieval-based learning that incorporates test-style questions has also been demonstrated to be an effective means for students to organize, synthesize, and retain information.[26-28] Studies indicate that student performance on practice tests is more likely to carry over to summative tests if question styles are similar and require similar types of cognitive processing.[28] Therefore, our quiz questions included both concept check and application questions adapted from board review books. Additionally, before the correct answers were revealed, students were asked to elaborate on why they had chosen their responses (i.e., explain why the correct answer was correct and why incorrect answers were incorrect). Elaboration has repeatedly been demonstrated to be an effective means of enhancing learning.[4]

One important limitation in group work is the propensity of students to use a divide-and-conquer approach. To avoid division of tasks, student groups were monitored and encouraged to come to collective agreement on the product under development. Students were also aware that their contribution to small-group activity was monitored, and a rubric summarizing their contribution, attitude, and inclusiveness was completed twice during the course.

Survey evaluation of this activity included a convenience sample of 23 students. As our medical school includes nine geographically distributed campus sites, evaluation is logistically very challenging and requires multiple levels of approval to gather student input statewide. Students providing feedback were all enrolled at our campus center and may not have fully represented attitudes of the entire first-year class participating in the activity.

Because all students in the new curriculum completed this activity, there was no opportunity to conduct a randomized controlled trial. This project could be strengthened by including such analysis, which is suggested for others incorporating this activity for the first time. Additional data would be useful in determining whether learning outcomes are enhanced when compared to more traditional approaches (e.g., lecture only).

In light of curricular reform efforts, the role of faculty in medical education has been transformed. Faculty are being asked to go beyond delivery of content and to apply more energy and effort in the process of developing innovative and engaging exercises to guide student learning. Our observations are that medical students often find themselves stressed and overwhelmed with the amount and level of course content. To help students experience success in their courses, it is important for faculty to creatively develop class activities that incorporate learning strategies substantiated by evidence. This exercise promotes engagement with course material and, at the same time, involves students in effective learning strategies, including collaboration, peer instruction, retrieval practice, and elaboration.[4] Authoring this type of learning resource can be extremely time consuming. Therefore, sharing of effective learning exercises, such as this nephron-mapping activity, is of value to physiology educators at all levels of instruction.

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