ORIGINAL ARTICLE

Exploring Prospective Teachers' Mental Models of Nephron Structure and Urine Formation through Drawing Analysis

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Abstract: The purpose of this study was to examine prospective biology teachers' drawings of the structure of the nephron and the stages of urine formation to determine their conceptual knowledge and to identify misconceptions based on these drawings. This research was conducted using a case study, a qualitative research design. The study group consisted of 32 prospective teachers studying in the biology teaching program at a state university in Turkey. The prospective teachers' drawings and semi-structured interviews were used as data collection tools. The drawings were evaluated using content analysis using a researcher-developed rubric. In this rubric, correct and complete drawings were scored separately with 2 points, incomplete and incorrect drawings with 1 point, and no drawing with 0 points. These drawings were reported using frequency and percentage distributions. Interview data was analyzed using content analysis. Based on the results obtained from both the drawings and the interviews, majority of prospective teachers knew the basic structures of the nephron, but they made errors in the detailed sections (collecting duct, vascular structures). While filtration in the urine formation process was partially explained correctly, there were serious misconceptions about the reabsorption and, especially, the secretion steps.

Science Insights Education Frontiers 2026; 32(2):5213-5227.
DOI: 10.15354/sief.26.or171

How to Cite: Özay Köse, E. (2026). Exploring prospective teachers' mental models of nephron structure and urine formation through drawing analysis. Science Insights Education Frontiers, 32(2):5213-5227.

Keywords *Nephron, Urine Formation, Drawing Technique, Interview, Prospective Teachers*

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Conflict of Interests: *None*

Funding: *No funding sources declared.*

AI Declaration: *The author affirms that artificial intelligence did not contribute to the process of preparing the work.*

Introduction

BIOLOGY EDUCATION requires learning complex concepts related to understanding the structure and functions of living things. One of the most important functions of the excretory system is to maintain the body's internal balance (homeostasis) by removing waste products and excess water resulting from metabolism. Within the excretory system, the kidneys and nephrons maintain the body's fluid, ionic, and pH balance by regulating the filtration, reabsorption, and secretion stages of urine formation (Sherwood, 2016).

Learning about the excretory system not only helps students understand physiological mechanisms but also helps them gain awareness of daily life and health. One of the main reasons this topic is considered important in biology education is that it raises students' awareness of topics directly related to life, such as kidney health, water-salt balance, nutrition, and kidney diseases (Guyton & Hall, 2011). Furthermore, the excretory system is directly linked to other topics such as cell metabolism and the circulatory system. Through these connections, students can better grasp the interdisciplinary nature of biology. Considering urine formation not only as a biochemical process but also within a holistic systemic interaction develops students' scientific thinking and intersystem skills (Çepni, 2014).

In conclusion, addressing the excretory system in biology teaching constitutes an important learning area for both the acquisition of basic biological knowledge and health and life skills. Therefore, it is crucial for students and prospective biology teachers to learn this subject accurately, understandably, and supported by scientific processes. This requires prospective teachers to prioritize teaching methods that will address misconceptions when teaching the subject.

The excretory system, specifically the structure of the nephron and the process of urine formation, is one of the areas where students frequently encounter misconceptions in biology teaching (Özatlı, 2006). Tekkaya et al. (2000), in their study investigating prospective biology teachers' misconceptions about excretory systems, found that the candidates held misconceptions on these topics based on the questions they asked about them.

The literature emphasizes that preservice teachers' misconceptions can be transmitted to future students (Kind, 2004). Therefore, preservice teachers' conceptual competence is critical. In biology, abstract topics such as cell organelles, systems, and physiological processes become more understandable through visualization. Novak's (1998) concept map approach and Mayer's (2005) multimedia learning theory support the importance of drawings in learning. Drawings are powerful tools that make students' mental models visible (Ainsworth, 2006). According to the constructivist approach, individuals concretize learning by reflecting their own cognitive schemas

through drawings. In summary, students and preservice teachers are prone to misconceptions, especially in human physiology. When such misconceptions are observed in preservice teachers, they pose the risk of incorrect transfer in future teaching processes. Therefore, examining preservice teachers' mental models is critical.

Mental models refer to the cognitive representations individuals have about a particular phenomenon or concept. Students and preservice teachers develop mental models based on their own experiences and educational processes when making sense of abstract biological processes. However, these models often do not align with scientific knowledge and may contain misconceptions (Gentner & Stevens, 1983). At this point, drawing is an effective tool for making preservice teachers' mental representations visible. Drawings can easily identify preservice teachers' knowledge levels and misconceptions about any topic (Dempsey & Betz, 2001; Gul & Ozay Kose, 2021; Patrick and Tunnicliffe, 2010; Reis, Tunnicliffe et al., 2002).

One of the most significant advantages of the drawing technique is that it allows individuals to express their thoughts through visual representations, rather than relying solely on verbal expression. While verbal explanations are often superficial, drawings concretely demonstrate how students construct knowledge and sequence processes (Pridmore & Bendelow, 1995). Drawings are powerful tools that make students' mental models visible (Nugraha, 2016). According to the constructivist approach, individuals embody learning by reflecting their own cognitive schemas through drawings. In this context, drawing is used not only as an assessment tool but also as a learning-supporting strategy in the instructional process.

Research shows that using drawing techniques in biology teaching is effective in uncovering students' misconceptions, encouraging conceptual change, and better understanding intersystem relationships (Reiss & Tunnicliffe, 2001, Köse 2024). Furthermore, drawing activities improve preservice biology teachers' visualization skills and contribute to their ability to present concepts more clearly and understandably to students in their future professional lives (Dempsey & Betz, 2001). In conclusion, using drawing techniques to explore preservice teachers' mental models of the excretory system is a powerful method for determining both their current knowledge and misconceptions. Drawing techniques are important not only for assessing learning outcomes but also as a pedagogical tool that enables preservice teachers to more deeply understand scientific processes.

The purpose of this study is to examine pre-service biology teachers' drawings of the structure of the nephron and the stages of urine formation to reveal their conceptual knowledge and to identify misconceptions based on these drawings.

Research Questions

1. Which structures are correct, no drawing, or incorrect in the pre-service biology teachers' drawings of the structure of the nephron?
2. Which structures are correct, no drawing, or incorrect in the pre-service biology teachers' drawings of the stages of urine formation?
3. What is the relationship between the pre-service teachers' drawings and the conceptual explanations obtained through the interviews?

Method

Research Model

This research was conducted using a case study, a qualitative research design. Drawings were examined to uncover the mental models of the preservice teachers.

Study Group

The study group consisted of 32 preservice teachers studying in the biology teaching program at a state university in Turkey. Participants were selected through purposive sampling. Their ages were between 20 and 21. They had been taught the topic of the human urinary system during the previous year. To understand the reasons for the choices and omissions in the drawings, interviews were conducted with six prospective teachers who owned papers with missing and unclear drawings. The reason for limiting the number to six prospective teachers was that the missing and meaningless drawings were very similar, so it was thought that choosing someone with these drawings would be sufficient, as well as time constraints.

Data Collection Tools

Drawings: Participants were given the task of "Draw the structure of a nephron in detail and write the names of its parts on them" and "Diagram the steps of urine formation on a nephron." Biology preservice teachers were given 40 minutes to complete their drawings, allowing them to draw the structure of the nephron and the steps of urine formation. Before the drawing session, the following statement was made: "You will not receive any points for this work. Please do not copy each other's drawings. We are only interested in your knowledge of the human excretory system. Furthermore, whether the drawing is artistic or not is not important."

Semi-Structured Interviews: Interviews were conducted with six volunteer preservice teachers to understand the reasons for the preferences and omissions in the drawings. The interviews focused on two main questions:

Table 1. Analysis of Drawings Related to The Structure of the Nephron.

	0 Point (No drawing)		1 Point (Incomplete/incorrect)		2 Point (Correct/Complete)	
Structures	**f**	**%**	**f**	**%**	**f**	**%**
Bowman's capsule	10	%31	10	%31	12	%38
Glomerulus	11	%34	7	%22	16	%50
Proximal tubule	9	%28	9	%28	14	%44
Loop of Henle	8	%25	12	%38	12	%38
Distal tubule	10	%31	12	%38	10	%31
Collecting duct	12	%38	11	%34	9	%28
Capillaries	14	%44	10	%31	8	%25

1. What are the parts of the nephron, and which parts did you find difficult to draw?
2. How does urine formation occur, and which parts did you find difficult to draw?

Data Analysis

Drawings were evaluated using content analysis using a researcher-developed rubric. Correct and complete drawings were scored separately with 2 points, incomplete and incorrect drawings with 1 point, and no drawing with 0 points. These were reported using frequency and percentage distributions. Interview data were analyzed using content analysis.

To ensure consistency, the drawings were evaluated by a biology educator other than the researcher, and the minimum 70% consistency criterion specified by Miles and Huberman (1994) was used; in the current study, consistency between coders was found to be 92%, demonstrating the reliability of the study. Finally, for confirmability purposes, all data collected during the study were stored and made available for review when necessary.

Findings

Drawings Related to the Structure of the Nephron

In the analysis of data obtained from the drawings of pre-service biology teachers in the study, the first research question related to the structure of the nephron was examined. Each structure is presented in **Table 1**. In the representation of numerical values, the number (f) and the percentage (%) of preservice biology teachers indicating each structure in the study are presented in separate columns in the tables.

When drawings of the structures that make up the Malpighian corpuscle were examined, 50% of the preservice teachers accurately and com-

Table 2. Analysis of Drawings of Urine Formation.

	0 Point (No drawing)		1 Point (Incomplete/incorrect)		2 Point (Correct/Complete)	
Stages	**f**	**%**	**f**	**%**	**f**	**%**
Filtration	14	%44	6	%19	12	38
Reabsorption	15	%47	7	%22	10	31
Secretion	17	%53	7	%22	8	25

pletely depicted the glomerulus, while 38% accurately and completely depicted the Bowman's capsule. Thirty-one percent of the participants drew the Bowman's capsule, and 22% incompletely. Preservice teachers in this group generally drew the glomerulus and Bowman's capsule, but they did not label them or correctly demonstrate the connection between them. For example, incomplete drawings were observed, such as showing the Bowman's capsule with only a single "line" and omitting the glomerulus. Nearly 30% did not draw the glomerulus or Bowman's capsule at all.

When examining the tubules continuing into the Bowman's capsule, the proximal tubule (44%), the loop of Henle (38%), and the distal tubule (31%) were drawn correctly, and their names were written correctly. However, although the majority of preservice teachers drew the tubular parts of the nephron in their drawings, 38% did not name the loop of Henle and the distal tubule, and 28% did not name the proximal tubule or placed it incorrectly. Approximately 30% did not show any part of the tubular structure in their drawings, connecting the Bowman's capsule directly to the urinary collecting duct.

Only a small minority of prospective teachers correctly drew the collecting duct and vessels. 44% of prospective teachers did not draw capillaries at all, while 38% did not include the collecting duct in their drawings. Of the 31% who showed vessels incompletely, most generally showed vessels within the glomerulus but neglected to draw vessels surrounding the tubules. The majority of those who drew the collecting duct incompletely (34%) drew a duct but did not label it.

These findings suggest that prospective teachers have a general understanding of the structure of the nephron, but struggle to understand and translate the detailed relationships into drawings. This suggests a misunderstanding of the functional relationships of the structures.

Drawings Related to the Stages of Urine Formation

In the analysis of data obtained from biology teacher candidates' drawings in the study, the second research problem regarding the stages of urine formation was examined. Each stage of urine formation is presented in **Table 2**.

In displaying numerical values, the number (f) and proportion (%) of biology teacher candidates indicating each stage in the study are presented in separate columns in the tables.

An examination of the preservice teachers' drawings revealed that only a small portion of the participants were able to accurately and progressively express the urine formation process. Approximately 38% of the participants correctly linked the steps of filtration, 31% reabsorption, and 25% secretion, relating them to the nephron structure. This group correctly located the filtration process in the Bowman's capsule, reabsorption, and secretion in the tubules. The majority, however, incompletely represented some stages in the process or produced misconceptions. Those who provided incomplete drawings confused the locations where filtration, reabsorption, and secretion occur. Furthermore, they ignored details by describing filtration only as "wastes." They also limited reabsorption to water and omitted other substances such as glucose, amino acids, and ions. Secretion was virtually ignored in the drawings (53%). Some preservice teachers drew urine produced "readily" in the Bowman's capsule. Nearly half of the prospective teachers were unable to create any drawings related to urine formation.

Interview Analysis with the Prospective Teachers

Semi-structured interviews were conducted with six volunteer prospective teachers to understand the reasons for their preferences and omissions in drawings related to the structure of the nephron and urine formation. The data obtained from the interviews were analyzed using content analysis and categorized under three main themes: (1) Knowledge gaps, (2) Difficulties with drawing technique, and (3) Conceptual confusion and misconceptions.

Knowledge Gaps

PT-2: "Teacher, I remember it being explained in class, but I don't know the exact function of the loop of Henle, so I didn't show it in the drawing."
PT-5: "I didn't include the other stages because I remembered that urine is only filtered in the glomerulus."
PT-1: "I didn't know the role of the collecting duct in urine formation, so I didn't include it."
PT-4: "The shape of the nephron isn't completely clear in my mind, so I drew it simply."

A significant number of prospective teachers reported difficulty recalling the details of the nephron's structure. Uncertainties regarding the function of the loop of Henle and the processes of reabsorption were particularly pronounced. These gaps in knowledge were also reflected in their drawings.

Difficulties Related to Drawing Technique

PT-3: "Actually, I know, but drawing takes a lot of time and I can't do it well, so I simply showed it."
PT-6: "I spend a lot of time drawing, and I chose not to include details because I'm not practiced."

Some students stated that they had difficulty drawing biological structures and therefore skipped details. These statements demonstrate that drawing is an important aspect of conveying information.

Conceptual Confusion and Misconceptions

PT1: "I thought reabsorption was also a part of urine formation, so I wrote that urine was formed a second time."
PT4: "I didn't show the other structures because I thought the fluid coming out of the Bowman capsule was urine."
PT5: "I thought secretion was exactly the same as urine being expelled."
PT3: "I thought any fluid coming out of the glomerulus was urine."

Some students made incorrect connections in their drawings due to a lack of understanding of the stages of urine formation. This was particularly evident in the reabsorption and secretion processes. According to the student candidates, these misconceptions or conceptual confusions were reflected in their drawings.

Based on these three themes, we can summarize that the interview findings reveal that the deficiencies in the preservice teachers' drawings stem not only from a lack of knowledge but also from a lack of confidence in their drawing skills and misconceptions. Students' statements indicate that the structure-function relationship was learned superficially and details were ignored.

Discussion

This study examined preservice biology teachers' mental models of nephron structure and urine formation through drawings. The findings provided important insights into their knowledge, conceptual understanding, and misconceptions, highlighting their misconceptions. The findings revealed that preservice teachers' mental models of nephron structure and urine formation were incomplete, fragmented, and contained misconceptions. This suggests that the information they will convey to their students in the future is at risk of similar deficiencies. Therefore, it is crucial that teacher training programs incorporate more visual, modeling, and drawing-based activities into the teaching of physiological processes. The findings indicated that only a small portion of preservice teachers accurately and completely captured the neph-

ron structure and urine formation process in their drawings. The majority of pre-service teachers either did not show the necessary parts in their drawings at all or presented incomplete or incorrect drawings.

When examining findings regarding the structure of the nephron, the correct drawing of the Bowman capsule, glomerulus, and tubules demonstrates that prospective teachers are aware of the most fundamental structures. However, the omission of the capillaries and collecting duct by most prospective teachers demonstrates that they struggle to grasp the functional integrity of the nephron. In particular, the capillary network within the nephron is frequently overlooked. This finding is consistent with a study by Yip (1998), who identified similar errors in students. Another common misconception is the belief that the nephron functions solely as a filter. However, the nephron is an active structure that maintains homeostasis through selective processes such as reabsorption and secretion, as well as waste filtration (Guyton & Hall, 2011).

When looking at the findings regarding the urine formation process, the majority's accurate description of the filtration step indicates that prospective teachers understand the beginning of the process. However, the most common misconception revealed by this finding is the belief that urine formation consists solely of glomerular filtration. Prospective teachers appear to view urine formation as a single "production process" and ignore the reabsorption and secretion steps. This finding is consistent with studies by Yip (1998) and Tekkaya et al. (2000), which identified similar errors in students. Interviews with prospective teachers revealed that they believed urine was formed "readily" in the kidneys and had difficulty grasping the filtration and reabsorption steps. This finding is consistent with studies in the literature demonstrating that prospective biology teachers generally tend to learn physiological processes superficially (Özatlı & Bahar, 2010). Furthermore, misinterpreting reabsorption as "the second formation of urine" indicates that students struggle to establish the structure-function relationship. Similarly, Yip (1998) emphasized that students struggle to conceptualize the sub mechanisms of biological processes, thus developing faulty mental models. In summary, the preservice teachers' drawings demonstrate that they do not fully grasp the processes of filtration, reabsorption, and secretion, and that they are particularly lacking or incorrect in their understanding of molecular mechanisms. This supports misconceptions about the "abstract nature of biological processes" frequently reported in the literature (Gilbert, 2005; Duit, 2007). Furthermore, some preservice teachers misunderstood the fluid transfer between Bowman's capsule and tubule or completely neglected reabsorption. Awareness of such deficiencies is crucial for teachers to identify potential misconceptions students may encounter in biology classes. Furthermore, limiting reabsorption to water and often ignoring the secretion step reveals the prevalence of misconceptions or lack of knowledge. Furthermore, stu-

dents often believe that urine consists solely of water and urea, and are often unaware that ions, toxic substances, and other metabolic wastes are excreted in urine. This demonstrates a lack of understanding of the biochemical aspects of urine formation.

Data obtained using the drawing analysis indicate that students' lack of knowledge, as well as a lack of confidence in their drawing skills and a tendency to simplify complex structures, are also significant factors. Interview findings indicate that students often skip details due to "not remembering the material completely" or "fear of drawing incorrectly," demonstrating that drawing-based assessments involve not only cognitive but also affective dimensions. This result suggests that students should be supported in the process of visualizing concepts, as Çepni (2014) emphasized regarding the use of multiple representations in science education.

Conclusion and Recommendations

The vast majority of prospective teachers know the basic structures of the nephron, but they make errors in the detailed aspects (distal tubule, collecting duct, and vascular structures). While filtration is partially described accurately during the urine formation process, there are serious misconceptions about reabsorption and, especially, secretion. In conclusion, this study demonstrates that drawing is a powerful tool for exploring prospective teachers' conceptual understanding. The fact that the drawing exercise was conducted only once in this study and that only the drawing technique was used to assess conceptual understanding is considered a limitation. Therefore, it should be noted that preservice teachers' drawings reflect not only their knowledge level but also their conceptual misconceptions and emotional tendencies. In this context, future studies could explore a more in-depth conceptual profile by combining conceptual tests and individual interviews with drawings.

Drawing and related techniques should be regularly used in classrooms to support prospective teachers' understanding of biological processes. These methods help identify misconceptions by solidifying students' mental models. Misconceptions identified through drawing analysis should be specifically addressed during the teaching process. Using concrete examples and explanations, particularly for processes such as reabsorption and urine concentration, can prevent misunderstandings. Animations, concept maps, and three-dimensional models illustrating the structure of the nephron and the steps of urine formation should be made available to prospective teachers.

Future studies should focus more on visual material development and drawing-based teaching practices in physiology subjects. Comparative studies could be conducted with prospective teachers from different universities. Furthermore, a limitation of this study was that the impact of development in

drawing skills on students' conceptual understanding was not examined. Therefore, the impact of drawings on teaching success could be examined through experimental designs. The effects of different teaching methods (e.g., problem-based learning, laboratory-based teaching) on conceptual understanding of nephron and urine formation could be investigated. Long-term follow-up studies based on student drawings could be conducted to examine conceptual change processes. The effectiveness of drawing and concept mapping techniques in other biology subjects could also be evaluated comparatively. Furthermore, in this study, drawings were evaluated by interviewing some of the participants. In larger studies, interviews could be conducted with all participants who drew.

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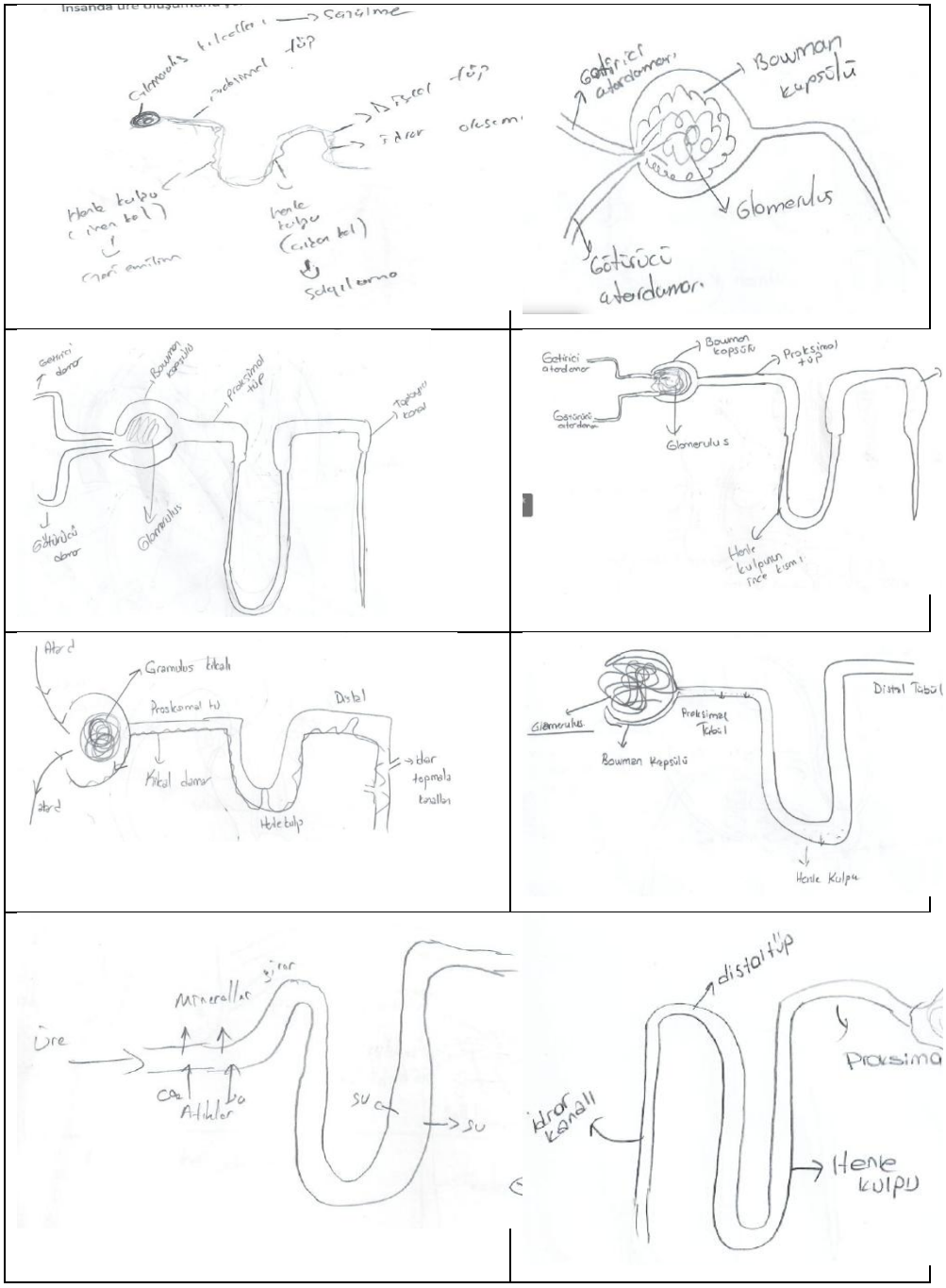
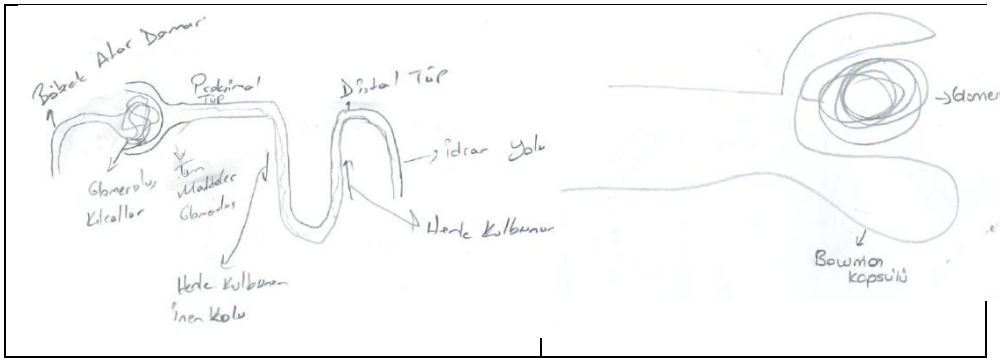
Received: October 09, 2025
Revised: October 25, 2025
Accepted: November 22, 2025

APPENDIX: Sample Drawings




Böbrek Atar Damar
Proksimal Tüp
Distal Tüp
İdrar Yolu
Glomerulus Kılcallar
Henle Kulbunun İnen Kolu
Bowman kapsülü