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A Tool for Helping Veterinary Students Learn Diagnostic Problem Solving

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Abstract

This study describes the result of implementing the Problem List Generator (PLG), a computer-based tool designed to help veterinary students learn diagnostic problem solving in clinical pathology. Participants included 421 veterinary students. The comparison group of 334 students did not use the PLG at all, one experimental group participated in PLG-based case-discussion sessions, and the other used the PLG for case-discussion sessions and for homework. Both treatment groups scored significantly better on the final exam ($p = .001$ and $.000$ respectively) than the comparison group. The findings suggest that providing an expert problem solving process to students, and ensuring that both students and teachers use the same format for representing the problem space, improves student problem solving ability.

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A Tool for Helping Veterinary Students Learn Diagnostic Problem Solving

You aren't feeling well, so you go to your doctor. A physical exam reveals nothing obvious, so blood and urine samples are sent to the lab. When the results come back, your doctor has a problem. The extent to which that problem is resolved satisfactorily (and, perhaps, your health) depends on your doctor's ability to interpret the data that have been collected. Clinical problem solving is the process of turning all the information available to the physician into a diagnosis and treatment plan. Clinical pathology involves the sub-problem of interpreting the laboratory data, which we refer to as diagnostic problem solving.

Smith and Ragan (1999) define problem solving as "the ability to combine previously learned principles, procedures, declarative knowledge, and cognitive strategies in a unique way within a domain of content to solve previously unencountered problems" (p. 132). Jonassen (2000) suggests that problem solving involves two processes: (a) the construction of a mental model of the problem (the problem space), and (b) activity-based manipulation of the problem space. He argues that general models of problem solving have proven inadequate for dealing with the rich diversity of problems faced by learners, as manifested by the fact that, although researchers tend to value problem solving as a learning outcome, many instructional design models and teaching theories provide sparse and/or non-specific guidance when it comes to instructional strategies for problem solving. There are many kinds of problems, varying in complexity and inextricably tied to the knowledge domain(s) associated with them.

Clinical problem solving and processes for teaching clinical problem solving frequently have been the object of inquiry in medical education. Expert medical practitioners in the field appear to automate expert tasks into *scripts,* obscuring underlying reasoning. This has caused some researchers to suggest that rather than spending excessive time learning underlying

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concepts and rules, students should focus on learning many diverse clinical scenarios and solutions (Schmidt, Norman, & Boshuizen, 1990), thereby acquiring these scripts themselves directly. Other research suggests that those who are best equipped to solve clinical problems do indeed have, and access robust structural knowledge in this domain (Bordage, 1994; Bordage & Lemieux, 1991). The latter view is commonly held among those who make a general study of teaching and learning (Gagné, Briggs, & Wager, 1992; Jonassen, 2000; Smith & Ragan, 1999).

Our domain is clinical pathology, with an approach to the discipline, described elsewhere (Bender et al., 2000), that emphasizes interpreting abnormal laboratory data in terms of *mechanisms of disease*. A mechanism of disease is a description of a disruption of normal physiology. For example, if lab data from blood work for a specific patient show anemia (low red blood cell count) and hypoproteinemia (low protein), one mechanism that might explain (cause) this type of data abnormality is hemorrhage. In a way, then, to require students to study clinical pathology at all is to commit to the viewpoint that knowledge of the component concepts, rules and principles involved in clinical problem solving is necessary; clinical pathology itself can be viewed as the study of such components.

There are perhaps as many approaches to teaching problem solving as there are areas of expertise. In medical education, research suggests that the two prominent curricula, problem based learning (PBL) and the traditional lecture based curriculum, produce distinct problem solving processes (Patel, Groen, & Norman, 1991). PBL generally involves presenting a group of students with a problem and requiring them to find the resources and knowledge required for solving it without formal instruction (presentation) of the underlying rules and concepts. Although the instructional presentation does not focus on component concepts, the research and problem solving process is consumed by immersion in those concepts. Thus, PBL can be said to

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focus on the discovery of underlying rules and concepts in a problem-based environment. The traditional curriculum, on the other hand, tends to focus on presentation and memorization of correlations between medical conditions, causes, and treatments (Albanese & Mitchell, 1993; Berkson, 1993; Norman & Schmidt, 1992; Rivarola, Bergesse, Garcia, & Fernandez, 1997; Rosing, 1997; Wilkerson, Hafler, & Liu, 1991). The PBL approach tends to result in students who use *backward* reasoning; they use comprehension of underlying rules and concepts to test hypotheses and arrive at solutions. Lecture-based medical curricula, on the other hand, tend to result in more *forward* reasoning, meaning that, when given a problem, students search their memories for a similar case, and apply it to the problem (Patel et al., 1991). Although the PBL approach might be argued to result in reasoning that is more effective for problem-solving (which inherently involves the unknown, to a certain extent), one potential disadvantage of the PBL approach is that students tend to spend more time exploring erroneous hypotheses than those who use the traditional approach (Patel et al., 1991). Mandin, Jones, Woloschuk, and Harasym (1997) propose a teaching strategy to benefit from the advantages of the PBL approach while side-stepping the disadvantage of straying down many errant logical paths. They suggest providing an *expert scheme* in the context of a problem when teaching diagnostics to students. This expert scheme is a framework or process for dealing with data; learners associate subordinate concepts and skills with that process/framework. Mandin et al. (1997) assert that if students learn knowledge in the context of an expert scheme, they will be more likely to remember the knowledge as it relates to the overall problem. This expert scheme might be described as a representation of the expert problem space/problem solving process. This perspective is also reminiscent of Collins, Brown, and Newman's popular concept of *cognitive apprenticeship* (1989). Among other things, they recommend providing control strategies, (the problem solving process is controlled – includes diagnosis, monitoring, and remediation), articulation (requiring students to articulate their knowledge), reflection (an ability to compare novice to expert solutions and processes), and appropriate sequencing (problems that increase in complexity and diversity).

The project described here is the result of a problem of our own – trying to help students enrolled in their second year of veterinary school to improve their diagnostic problem solving skills in the domain of clinical pathology. We set out to create a computer-based instructional tool that would provide expert guidance, and, thereby, we hoped, increase student problem solving ability.

To avoid reviewing basic principles and process of instructional design that will be familiar to most readers, while at the same time providing adequate detail for intelligent interpretation of our results, we will report our development process in terms of Briggs' (1984) Culture Four criteria for research in IT, as suggested by Driscoll and Dick (1999). These criteria call for researchers to (a) accurately classify the learning outcome being studied and supply objectives and test items, (b) use real curriculum materials (c) use materials that have been systematically designed and formatively evaluated, and (d) use tests that really measure the ability to classify examples and non-examples of the concepts. We will briefly characterize the development process and tools in an attempt to satisfy the first three criteria. The last is presented in the instruments section of the methodology.

Learning Outcomes

The instructional analysis involved many hours of interviews with experts and learners in clinical pathology. Most of these interviews entailed giving a representative medical problem to an expert or learner, and watching and recording their process for dealing with it (while asking questions). These interviews revealed an expert process that involved, a) identifying relevant history data, b) identifying abnormal data, and c) organizing data by causal mechanism. The subparts of this process are articulated below as learning objectives, categorized using Gagné's (Gagné et al., 1992) taxonomy: 1. Accurately identify diagnoses given a typical printout of clinical lab data (Problem Solving); 2. Organize data hierarchically according to how abnormalities and mechanisms affect each other (Problem Solving); 3. Identify individual effects of specific data abnormalities on specific mechanisms (Higher-Order Rules); 4. Identify individual effects of specific data abnormalities on other data abnormalities (Higher-Order Rules); 5. Identify individual effects of specific mechanisms on specific data abnormalities (Higher-Order Rules); 6. Explain individual effects of specific mechanisms on other mechanisms (Higher-Order Rules); 7. Name specific abnormalities given laboratory data (Verbal Information); 8. Identify sets of laboratory data as either normal or abnormal (Discrimination); 9. Differentiate between abnormalities and mechanisms (Defined Concept); 10. Identify and name specific mechanisms given laboratory data (Higher-order Rules); 11. Read and understand typical laboratory printouts in terms of layout, labeling, and terminology (Concrete concepts and discriminations); 12. Differentiate breed and species-specific information in terms of data abnormalities (Rules); 13. Define: data abnormality (Verbal Information); 14. Define: mechanism (Verbal Information). This set of objectives identifies what learners will do to solve a specific case, given the prerequisite domain knowledge. An instructional analysis involving all the prerequisite domain knowledge would obviously be extremely extensive.

Curriculum Materials

In developing the strategy, we turned to the instructional analysis, producing an expert schem*e* (Mandin et al., 1997) that would provide what might be considered an effective

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environment for enhancing the development of the learner problem space. Students are provided with a framework or process for dealing with data, and associating subordinate concepts and skills with that process/framework. The computer based instructional tool we developed became known as the Problem List Generator (PLG). The PLG interface embodies the instructional strategy. The four windows that provide the essential core function of the PLG are described as follows. Figure 1 contains relevant signalment (species/breed characteristics), history, and physical exam data, which together constitute the physical description of the patient and events leading up to the patient being seen by the clinician. From the screen shown in Figure 1, students identify and record relevant information, either by highlighting and pasting text directly from the paragraph narrative, or by typing their own descriptors into a dialogue box.

Once students have identified the data they consider to be relevant from the screen shown in Figure 1, they move to the second of the two data presentation windows, shown in Figure 2. This window presents the laboratory tests and results, and is designed to mirror a typical lab data sheet as might be seen by the student in practice. The student uses the middle pull-down menus to indicate whether or not the data is normal, and, in the right-hand column, under “abnormality name”, the student names the data abnormality. Most data abnormalities have a limited number of accepted names, one of which the student must enter correctly to move forward. The student must also identify all abnormal data before moving to the next step of the process. Prompts are given if students make three unsuccessful attempts either to name a data abnormality, or to move on to the next window, so that students don’t become stuck.

After students have identified and correctly named all data abnormalities, they proceed to the “construct problem list” window, as seen in Figure 3. In the right column of this window appear the observations and data abnormalities identified previously by the students. In the left

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hand grid, learners drag and drop data elements to arrange them in a hierarchical outline format; that which is above and to the left is shown to cause (or be supported by) that which falls below and to the right. The result is called a *problem list* and represents the case solution. Here the learner identifies mechanisms of disease, as based on prerequisite knowledge of physiology and pathology. By creating the problem list, learners unambiguously communicate their understanding of relationships between data abnormalities.

After completing the problem list to their satisfaction, learners make a diagnosis, and the problem list is submitted for credit. At this point, students compare their problem list to the expert problem list, as seen in Figure 4. Note that the expert problem list is identical in format to the student problem list, except that mechanisms are coded as core (new, and essential to this case), review (previously encountered essential mechanisms that are reviewed here) or framing (mechanisms that have not yet been formally covered in the course, but will be covered later, or are not central to the study of clinical pathology). The PLG contains other features and functionality, but the windows contained in figures 1-4 constitute the core instructional functionality of the program.

Systematic Design, Development, and Evaluation

Elsewhere, Danielson (1999), describes the design, development and formative evaluation of the PLG in great detail. In summary, the PLG accompanies a pre-existing course with a history of success and popularity with students and alumni. The course for which the PLG was designed uses a mechanism-based approach to diagnostic reasoning, as described by Bender et al. (2000) elsewhere. The PLG was designed to provide a means for students to complete and receive credit for their work, and to improve their diagnostic problem solving skills in clinical pathology. We used Dick and Carey’s (1996) instructional design model to guide the design and development process of the PLG. In addition to the Dick and Carey model, we followed Tessmer and Richey's (1997) more detailed contextual analysis procedure. Because our tool was computer-based, we combined the overall design process with Hix and Hartson's (1993) usability design model. A more in depth discussion of how interface design can be incorporated into instructional design is provided elsewhere (Danielson, Lockee, & Burton, 2000). Finally, we bolstered the formative evaluation process with recommendations from Tessmer (1993). Here we report the results of the summative evaluation.

Method

Variables

The dependent variables were learning impact and usability. Usability was subdivided as clarity and feasibility. The final exam was used as one indicator of learning impact. A questionnaire given in year 2001, and an interview with the instructor were also used to indicate impact (self-report). Clarity and feasibility data were gathered from the questionnaire.

Participants

There were 421 participants -- all the students who participated in VM 8414 between 1996 and 2001. All students have an undergraduate degree, and were recruited to the veterinary school using the same entrance requirements (G.R.E. scores, GPA, and entrance interview), and drawing from the same populations. Eighty-nine percent of each class's students were recruited from the two states with which the college is affiliated. The remaining 11% were recruited from out of state. Each class is roughly 70% female and 30% male. Each class is comprised of between 77 and 89 students.

Procedures

The Clinical Pathology course was taught using the following format throughout the period of the study: The course is designed around 21 lectures, 49 case discussion periods, 21 unannounced quizzes, and 90 case-based homework assignments. Lectures present component knowledge and skills necessary to understand the case homework. The unannounced quizzes are based on case homework assignments, and provide an incentive for completing the homework. The 49 case discussion periods, which are dispersed throughout the semester, are used to analyze the cases after they have been completed as homework by the students. Each student prepares one case for presentation to the class during the case discussion period, and discusses that case with an instructor prior to presenting it. Instructors present lectures, lead case discussion periods, and work individually with students to prepare their assigned case discussion presentations.

During the 1996 – 98 years, the course was taught as described above. Students were required to do homework, but did not turn it in or get credit for it. The pop quizzes, which amounted to half of the total grade, provided incentive for students to complete homework cases.

The course was taught in 1999 just as it had been taught in 1996-1998 with three exceptions. First, during 1999, the PLG design was finalized and the formative evaluation was completed. Some students in the 1999 class were recruited to participate in formative evaluation sessions of the PLG, but exposure to the PLG was minimal, involved primarily easy or previously-seen cases, and primarily occurred after the majority of the course had been taught. Students completed their case homework on paper as had been done in previous years. Second, 1999 differed from previous years in that the students were required to submit their homework assignments, and were given credit for doing so. (Thirty-three percent of the grade was now based on homework completion, 33% on pop quizzes, and 33% on the final exam.) The homework assignments were not evaluated; students were given full credit for simply turning them in. Because of the regular pop quizzes, it was not hypothesized that requiring that homework be turned in would affect student compliance with homework assignments – pop quizzes had already had that effect. Finally, prior to 1999 one of the two VM 8414 instructors retired, so a new faculty member was hired to teach one-third of the lectures. One instructor, who had taught the entire time, remained, and taught two-thirds of the lectures. Again, it was not thought that this change would affect student outcomes because the course retained the primary instructor, and the format did not change.

In 2000 the course was taught as it had been taught in 1999, except that students were, for the first time, given the option of using the PLG to complete their homework assignments, though they could continue to complete their assignments on paper if they wished. Bugs persisted, so only 10 of the 84 students used the PLG regularly to complete their homework. In 2000, however, the professor began to use the PLG to prepare and present case discussion lectures, and to prepare expert case solutions (to which students could compare their case solutions.)

In 2001, the course was taught as it had been taught in 2000, with two differences. First, the PLG was now more completely de-bugged, so most students used it to complete their homework. Of the 89 students in the class, 51 (59%) reported using the PLG for all of their cases. An additional 35 (21%) reported using the PLG for 90+% of their cases. Of the remainder of the class, only 9% (8 students) reported using the PLG for fewer than half of their cases. Second, due to the unexpected illness of one of the course instructors, the course was taught entirely by the first instructor (who initiated the development of the PLG, taught 50% of the lectures in 96-98, and taught 66% of the lectures in 99-2000).

Instruments

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The course final exam, used to measure learning impact, contains laboratory, signalment, history, and observation data for eight clinical cases. Five to seven multiple choice items accompany each case, in formats which include choosing the correct answer, choosing the incorrect answer, selecting all that apply, etc. An example of items from the final exam is found in Figure 5. Final exams are administered in class; they are equivalent from year to year, and are collected to prevent students from passing final exams on to subsequent classes.

The primary course instructor was interviewed informally on a number of occasions following the 2000 year, and during the 2001 year to determine her impression of any effect that implementing the PLG might be having. Because these were informal conversations, no interview protocol is provided.

All 2001 students were asked to complete a survey instrument designed to assess their perception of the impact, clarity, and feasibility of the PLG. Results from that survey are found in Table 2.

Results

Final Exam Data

Table 1 contains the means that were compared. We used a two-tailed independent samples T-test to make all means comparisons. The significance level used for all comparisons was .05, and P values are provided with all comparisons. Power calculations were based on an effect size of .3. This effect size was derived from the college grading scale. Using that scale, the difference between one grade and another (e.g. A and A-) is three percentage points. Although a rather arbitrary grading scale is not particularly indicative of knowledge, these differences have clear significance to the students. Students are aware of the grade cutoffs, and will often study with the goal in mind of improving a grade by one or more increments; therefore, we determined

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that one grade increment is a justifiable target effect size. In our context, a grade increment is, by definition, three percentage points, which also happens to be three-tenths of one SD for our population of 421 students. Therefore, for differences that are found to be significant, we consider an effect size of .3 or larger to be noteworthy.

Years Prior to 2000

Because there was no reason to suspect any systematic differences between years 1996, 1997, and 1998, the data from these years were combined for comparison to treatment years. Two changes, as described in the procedures section were introduced in 1999, though we did not feel these changes would prove significant. The final exam score difference between the 96-98 group and the 99 group did not, in fact, prove to be statistically significant, $t = 1.47$, $p = .142$, power = .67. Data from 1999 was, therefore, clumped with the 96-98 data, for comparison to the years in which the PLG was implemented.

Year 2000

The difference between final exam scores for 2000 ($M = 85.7$) and 1996-99 ($M = 81.6$) was statistically significant, $t = 3.47$, $p = .001$, effect size (Cohen's d) = .42.

Year 2001

The difference between final exam scores for 2001 ($M = 87.3$) and 1996-99 ($M = 81.6$) was statistically significant, $t = 4.94$, $p = .000$, effect size (Cohen's d) = .58. The difference between exam scores for 2000 and 2001 was not statistically significant, $t = 1.04$, $p = .302$, power = .50.

Faculty Member Interview

The faculty member teaching clinical pathology, and who initiated the development of the PLG, was interviewed to determine her impressions of the PLG's effect, if any, on learning.

Three main points emerged. First, she indicated that student problem lists and reasoning appeared to be better since implementation of the PLG. Students seemed to struggle less and be less frustrated. Meetings with students prior to their case presentations are much shorter and students now come prepared with more defensible and logical problem lists. Second, she indicated that her own problem lists (the expert list used for case discussions and PLG comparison) were becoming more precise and consistent. Finally, she indicated that her problem lists were becoming more detailed and complete. She did not indicate any disadvantages to PLG use.

Survey Data

The quantitative results for items 1-16 of the 2001 survey data can be found in Table 2. Five additional Likert-style items, asking for general impressions of the PLG, and providing students with antonym descriptors (such as wonderful and terrible, and interesting and uninteresting) were also included. These five items compared favorably with item means found in Table 2, with the lowest mean being 8.8, SD 1.2 and the highest being 9.4, SD 1. In addition to the Likert items, the survey also included five free-text items. Responses to those items are summarized as follows:

Item 22 asked that students indicate why they ranked specific items particularly negatively. Twenty-one participants responded to this item, with 3 of those indicating that they had made no negative comments. Of the remaining comments, 9 reported general technical problems, 8 reported frustration that they had to be connected to a network to run the PLG, 2 indicated that too many cases are required, 1 commented that "it makes you learn, which is hard", and 1 commented that it was difficult to learn to use.

Item 23 asked students to indicate what they liked best about using the PLG. Seventy-two participants responded, making 152 comments in all. Thirty-six respondents said the PLG helps organize thoughts or data, 26 indicated that it enhances completeness, 25 reported liking the expert feedback, 18 liked the fact that it enhances memorization of data abnormality names, 17 indicated that it's easy to use, 13 liked factors related to the convenience of using the PLG (e.g. that they could complete and turn in homework electronically), 8 made general statements about the benefit for learning (the PLG makes things "make sense"), 5 respondents reported liking the pictures, 3 liked the fact that cases are used, and 1 indicated that the PLG helps class presentation.

Item 24 asked students to indicate what they liked least about using the PLG. Seventy-two participants responded, making 82 comments in all. Twenty-three comments cited technical problems that were owed to the students' home or study environment (they didn't have a computer, or their computer was old and slow, etc.), 22 comments had to do with technical or situational problems beyond the students' power to control (e.g. the PLG tied up phone lines, the PLG was not Macintosh compatible, etc.), 18 comments related to interface or functionality problems (e.g. students couldn't select multiple lines in the problem list constructor window), 12 comments had to do with factors that increased the difficulty of the learning task and were deliberately designed into the PLG (e.g., the PLG requires correct spelling of data abnormality names), 4 comments were that too much homework is required and 2 respondents indicated that there was nothing they didn't like about the PLG.

Item 25 asked participants what they would change about the PLG if they could. Sixty students responded, with 64 suggestions being made in all. Thirty-two suggestions involved interface and functionality enhancements, such as making it easier to print, or to copy and paste throughout the program, 9 suggested that the PLG be made “faster”, 9 said not to change the PLG at all, 6 comments indicated that the PLG is too much work (either that it should not require correct spelling, etc., or that fewer cases should be required), 4 recommended that the PLG be available on more computers at the Vet School, 3 recommended using the PLG in more classes at the college, 2 indicated that their computers simply didn’t have enough RAM to run the PLG, 1 recommended expanding the PLG to include content-specific tutorials, and 1 recommended making the PLG work with Macintosh computers.

Item 26 asked for any other comments. Thirty-two participants responded, with a total of 35 responses. Thirty responses were either general positive statements like “great program” or specific indications that the PLG had helped learning. Four comments had to do with the PLG taking too much time or requiring too many cases, and one person indicated that the PLG had lost 3 homework assignments.

Item 27 asked that those using the PLG for fewer than 20% of their cases indicate why. There were 7 respondents, and 9 responses. Five responses had to do with computer access at the student’s home (no computer or a slow computer), 3 responses were that the cases could be done faster on paper, and 1 respondent indicated a general reluctance to use computers.

Discussion

The study investigated the effectiveness of the PLG – a software tool designed to improve student problem solving in the complex domain of clinical pathology. The results of the study suggest that students learning through classroom use of the PLG, as well as students using the PLG for both classroom and homework use earn higher final exam scores than those who do not use the PLG. It further suggests that students and instructor feel that the PLG is beneficial for

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learning, and that the students, in general, find the PLG to be usable, both in terms of clarity and feasibility.

Learning Impact

The data suggest that those who took VM 8414 in 2000 and 2001 performed significantly better on the final exam than their counterparts in previous years. Furthermore, the effect sizes of .42 and .58 respectively appear to be noteworthy. (We provided rationale in the Method section for considering an effect size of .3 or larger to be of consequence for this study.)

The fact that the research design was not experimental increases the possibility that differences between groups other than PLG use caused the differences in final exam scores. However, all students in the study were selected to the college the same way, and group assignment was a function of nothing other than the year that the students applied for vet school. Therefore, because we specifically designed the PLG to have a beneficial learning impact, and because the improvement corresponds with the implementation of the PLG, we are inclined to cautiously conclude that the PLG improved learning as indicated by final exam scores. This conclusion is supported by the questionnaire and interview data. Students generally felt that using the PLG helped them to understand clinical pathology better, as did the instructor.

Richie and Nelson (1996) observe that, with developmental research, it is more likely that unanticipated events will affect research procedures than with other kinds of research. This was consistent with our experience. In this case, bugs in the software in 2000 led us to have a year of partial PLG implementation, which we had not anticipated. Rather than ignore year 2000 data, as a non-typical implementation, we have reported the data. In 2000, the PLG was used for case discussion in class, but only about 10% of the students used it regularly for case homework. Because we anticipated that the primary benefit of the PLG would be in its use as a homework practice tool, we would have expected exam scores for 2000 to be more similar to prior years than to 2001 (when the PLG was used in class by all students, and for homework by almost all students). The opposite was the case, however. Although 2001 scores were higher than 2000 scores, and 2000 scores were higher than previous years, the statistically significant difference was found between 2000 and previous years rather than between 2000 and 2001. This could be due to several factors. First, the benefit from the instructors using the PLG for in-class discussion could be greater than anticipated. This hypothesis would be consistent with the primary instructor's observation that using the PLG increased her detail and consistency. It would seem reasonable that as detail and consistency of in-class presentations improved, student comprehension would improve as well. It is also possible that a type II error occurred, and that 2001 students really did do significantly better than their 2000 counterparts. Because the power of that particular comparison was .5, it seems possible that our research design was inadequate to detect a difference, and that we would have found a difference had there been more participants.

Clarity

The survey data suggest that, for the majority of the students, the PLG was easy to use, and easy to learn to use. This assertion is supported by responses to items 22-27, though clearly many students felt there was room for improvement in the interface. Many of the learners' interface improvement recommendations either have been implemented, or are in the process of being implemented. However, we have not chosen to make the PLG easier by removing learning requirements (such as the requirement for correct spelling) that were embodied in the PLG by design.

Feasibility

The fact that all but 9% of the class (eight students) used the PLG for more than half of their 90 cases in 2001 indicates that implementing the PLG was feasible. Furthermore, many students specifically commented that they felt the PLG was more convenient to use than simply doing the problem lists on paper. Finally, most suggestions for improving aspects of feasibility involved expanding or enhancing the use of the PLG (for example, making it available on more computers, or less dependent on a dedicated network line), while there were no suggestions that PLG use be discontinued.

The PLG as a tool to enhance problem space construction

The PLG forces students and instructors who use it to (a) identify all abnormal data, and (b) communicate what they understand to be the relationships between those data in a standard fashion. Learners can compare their explanation of differences to an expert explanation.

The PLG uses some instructional principles that are characteristic of constructivist theory. In some ways, it presents what Duffy and Cunningham (1996) refer to as "the problem as a stimulus for authentic activity" (p. 190). In this model, instead of *teaching*, the teacher/facilitator supports the student's learning "as skills are developed through working on the problem" (p. 191) At the same time, Duffy and Cunningham argue that discovery learning, scaffolding, cognitive apprenticeship, coaching and collaborative learning, all frequently referred to as constructivist methods, are only truly constructivist to the extent that they are used <u>not</u> to teach students what they "should do/know and when they should do/know it" (p. 191), but rather to "support the students in developing their critical thinking skills, self-directed learning skills, and content knowledge in relation to the problem" (p. 191). Because the PLG is used in the context of didactic content presentation (case discussion and lecture), and not in a PBL environment, and because the PLG requires that students identify all pieces of the problem prior to formally organizing that data, and that students communicate their understanding of relationships between data in a standard format, our approach is not constructivist. However, our experience with the PLG does imply that the general strategy of embodying expert help in the form of an expert scheme (Mandin et al., 1997), and guiding strategies associated with concepts of cognitive apprenticeship (Collins et al., 1989), can be fruitful in a computer-based environment.

Jonassen (2000) suggests that “the key to learning to solve problems is the problem space construction, because rich problem representations most clearly distinguish experts from novices and scaffold working memory . . .” (p. 82) The fact that the PLG appears to have been successful both as a presentation tool and as a practice/presentation tool, suggests that it might help clarify and standardize the representation of the problem space, both for teacher and learner. Perhaps more important than the specific layout of information in the PLG, is the fact that all the participants in the learning activity (teachers and learners alike) use the same set of data in constructing their explanation of the problem, and the same format for communicating it. Although specifics between solutions vary substantially, even between experts, the fact that a standard format is used to represent them ensures that differences between perceptions of problems are clearly articulated.

Limitations and future research

The similarity between the problems encountered through the PLG and problems encountered by practitioners is substantial. At the same time, the PLG case problems have been rendered simpler and more focused to teach clinical pathology (interpretation of laboratory data). Practitioners in the field have more data, and more decisions to deal with than the PLG provides. First, they have different (one would hope, richer) physical exam data because they personally examine the patient. Second, they have some flexibility in choosing what lab tests to run, and, therefore, might have less, more or different lab data than what the PLG presents. Third, they may choose to gather more data from radiographs and other types of imaging, electrocardiograms, etc. Fourth, in many cases, they can follow a patient's progress over time. Although some of the cases in the PLG follow specific patients over a period of time, most cases involve only the one-time data that is presented. Therefore, although PLG practice transfers well to the final exam, we have not yet had the opportunity to see how it transfers to a clinical environment. Future research will focus on how learning problem-solving sub-tasks (such as clinical pathology) transfer to the macro problem (clinical problem solving) of which the sub-problems are a part, or, in other words, how well this kind of practice will translate to the broader clinical problem solving environment.

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Table 1: Means and Standard Deviations for year to year comparisons

Year(s)	M±SD	*n*
1996-98	81.1±10.1	245
1999	82.9±8.9	89
1996-99	81.6±9.8	334
2000	85.7±10.3	84
2001	87.3±10.1	89

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Table 2

Means, standard deviation, median, maximum, and minimum by item for Year 2001

Questionnaire item:		M±SD	*Mdn*	Max.	Min.	*n*
1. Indicate the approximate percentage of cases on which you used the PLG. Include cases you worked on in a group, where the group used the PLG.	0% 100% 0 1 2 3 4 5 6 7 8 9 10 NA	8.7±2.5	10	10	1	86
2. When I use the Problem List Generator, I feel….	overwhelmed comfortable 0 1 2 3 4 5 6 7 8 9 10 NA	9.1±1.2	9	10	4	80
3. Learning how to use the PLG was….	difficult easy 0 1 2 3 4 5 6 7 8 9 10 NA	8.5±1.9	9	10	1	80
4. Navigating through a case using the PLG is….	confusing clear 0 1 2 3 4 5 6 7 8 9 10 NA	9.1±1.2	9	10	5	80
5. Using the Problem List Generator made me account for more lab data than I otherwise would have accounted for.	Less Same More 0 1 2 3 4 5 6 7 8 9 10 NA	8.9±1.5	10	10	5	80

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Questionnaire item:		M±SD	*Mdn*	Max.	Min.	*n*
6. Using the Problem List Generator made my problem lists more precise than they would have been otherwise.	Less Same More 0 1 2 3 4 5 6 7 8 9 10 NA	9.0±1.3	10	10	5	80
7. It is hard to remember what all the buttons and menus of the PLG do.	Yes/Too hard No 0 1 2 3 4 5 6 7 8 9 10 NA	9.5±1.1	10	10	5	79
8. Overall navigation (getting around in the program) is….	irritating easy 0 1 2 3 4 5 6 7 8 9 10 NA	8.9±1.5	9	10	2	80
9. I am frustrated by technical problems with the PLG.	frequently never 0 1 2 3 4 5 6 7 8 9 10 NA	7.7±2.0	8	10	2	80
10. The PLG makes doing my Clinical Pathology homework more enjoyable than doing it on paper.	definitely not absolutely 0 1 2 3 4 5 6 7 8 9 10 NA	8.9±1.8	10	10	2	80

Questionnaire item:		M±SD	*Mdn*	Max.	Min.	*n*
11. The PLG makes doing my Clinical Pathology homework more worthwhile than doing it on paper.	definitely not absolutely 0 1 2 3 4 5 6 7 8 9 10 NA	8.9±1.5	9	10	3	80
12. I like being able to do my problem lists on a computer.	definitely not absolutely 0 1 2 3 4 5 6 7 8 9 10 NA	9.3±1.4	10	10	1	80
13. I like being able to do my problem lists online.	definitely not absolutely 0 1 2 3 4 5 6 7 8 9 10 NA	8.3±2.2	9	10	1	79
14. I like having my problem lists turned in automatically as soon as I finish them.	definitely not absolutely 0 1 2 3 4 5 6 7 8 9 10 NA	9.6±1.1	10	10	5	80
15. Using the problem list generator helps me to organize my thoughts about a case.	definitely not absolutely 0 1 2 3 4 5 6 7 8 9 10 NA	9.1±1.4	10	10	3	80

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Questionnaire item:		M±SD	*Mdn*	Max.	Min.	*n*
16. Using the problem list generator makes understanding clinical pathology….	harder 0 1 2 3 4 5 6 7 8 9 10 easier NA	8.9±1.4	9	10	4	80

Figure 1: First Data Presentation Screen

Figure 2: Second Data Presentation Screen – Laboratory Data

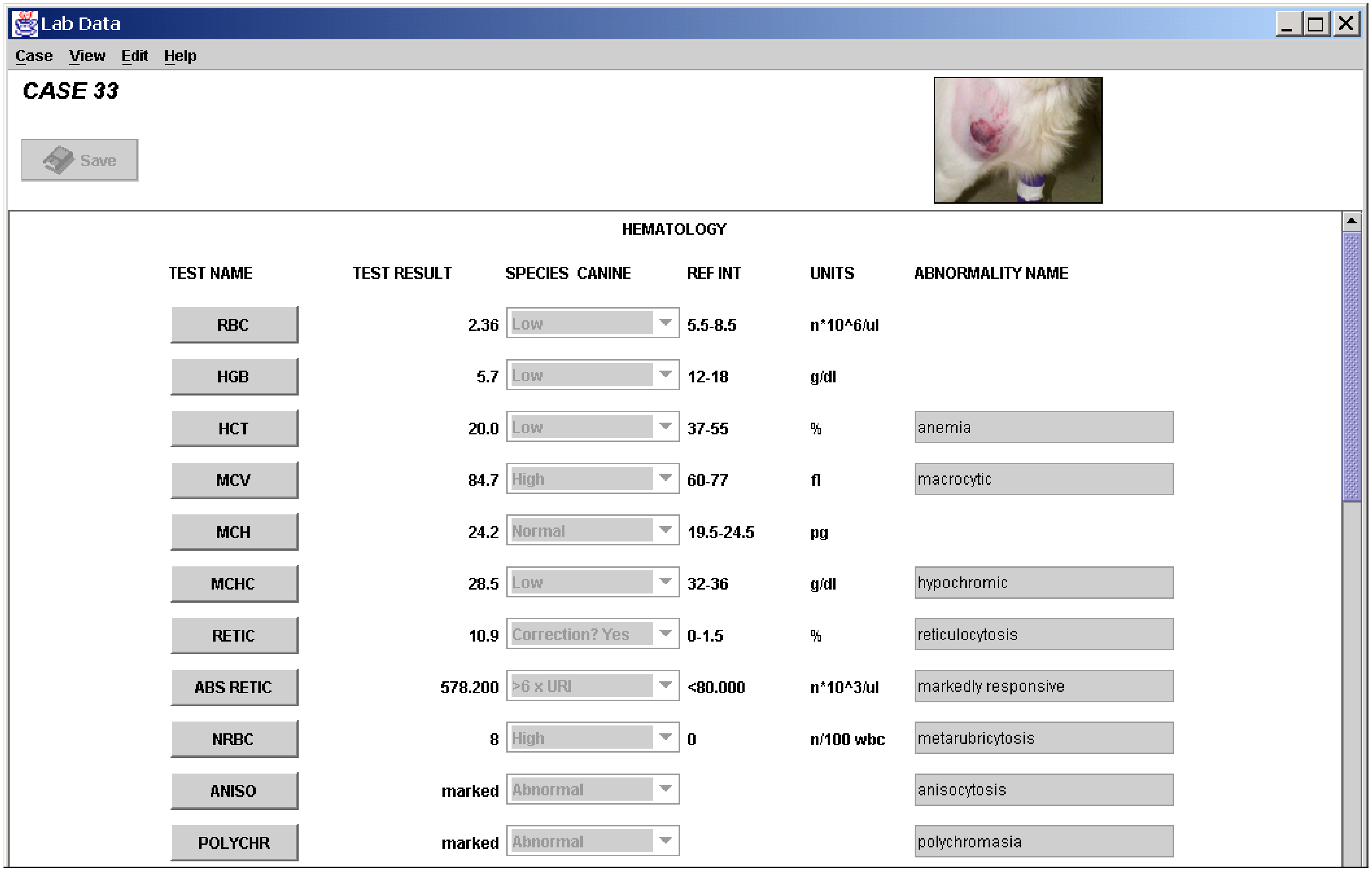

Figure 3 – Data Synthesis

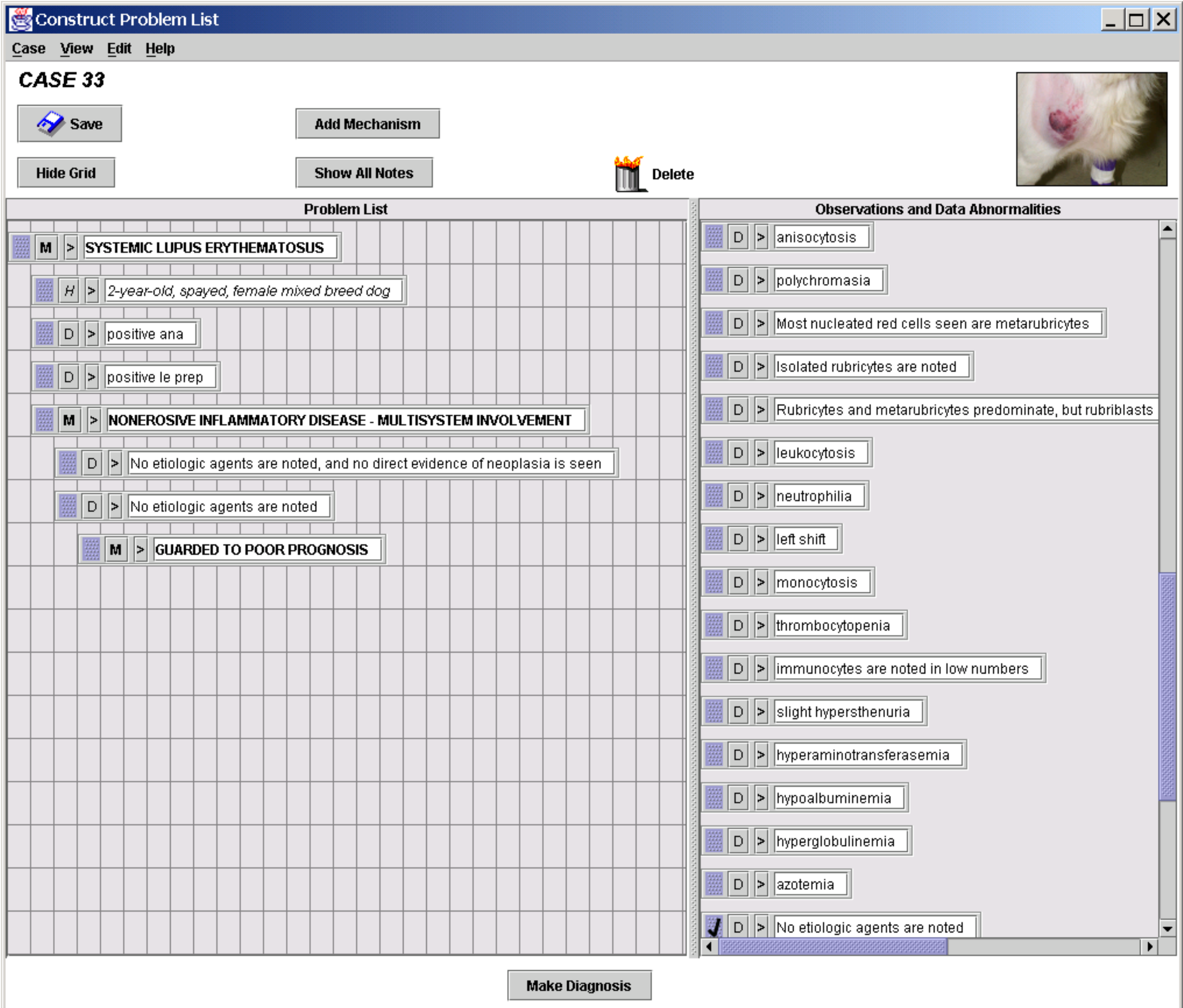

Figure 4 -- Feedback

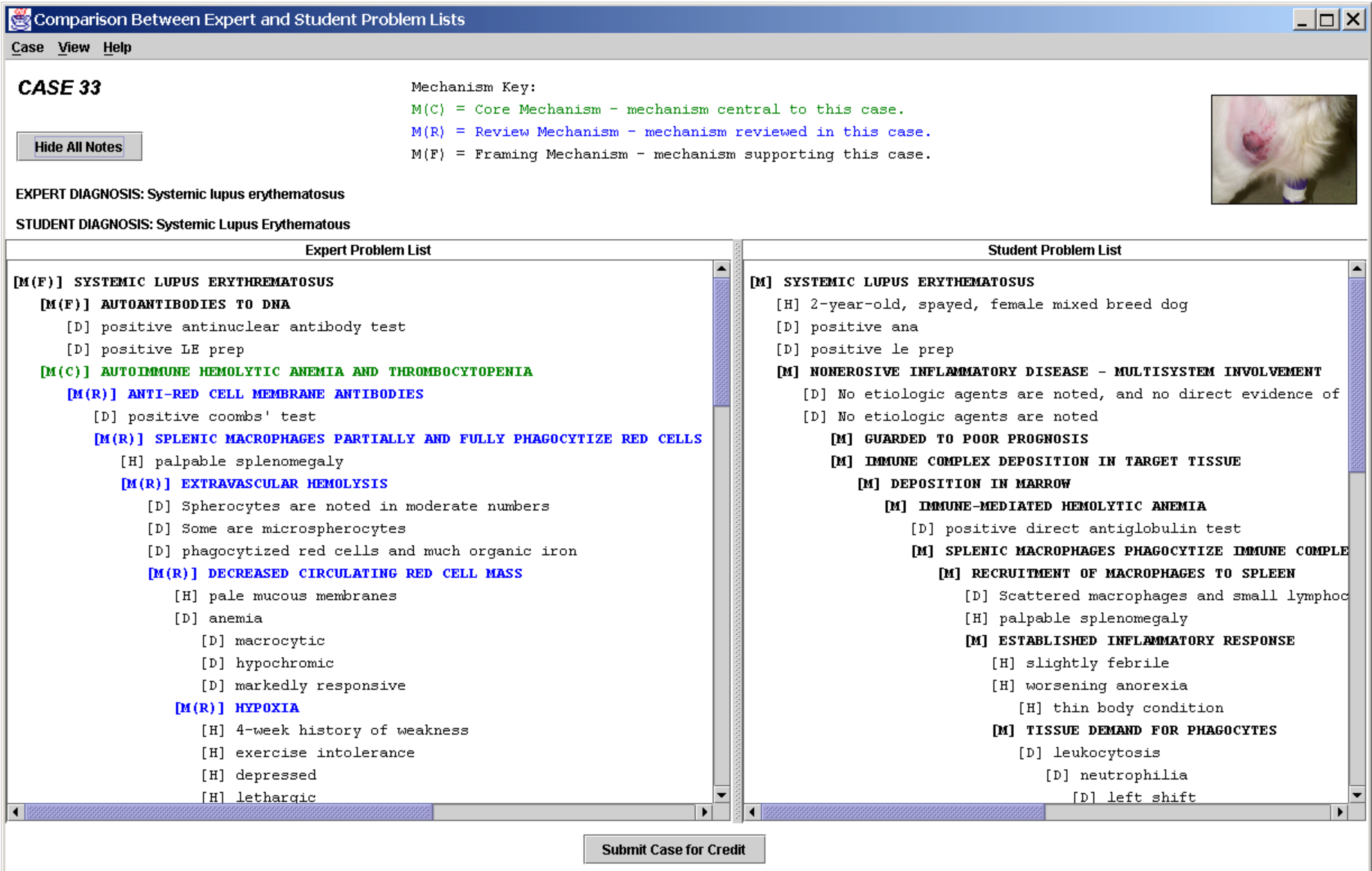

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Figure 5: Final Exam Excerpt

You are presented with a 6-year-old, spayed female poodle. The owner complains that the dog just 'isn't right." He says that he can't put his finger on when it started, but for the last 2 months or so, the dog is not eating as enthusiastically, occasionally vomits, and periodically has loose stools. Two weeks ago, she seemed brighter, but now she is progressively weaker, lethargic and occasionally urinates on the living room rug. On physical examination, you note a depressed, dehydrated patient, with a weak femoral pulse, bradycardia, and hyperpnea.

		HEMATOLOGY	Canine Ref. Interval	Units
RBC		6.10	5.5-8.5	n x 10 ^{6}/µl
HGB		14.1	12-18	g/dl
HCT		42.0	37-55	%
MCV		68.9	60-77	fl
MCH		23.1	19.5-24.5	pg
MCHC		33.6	32-36	g/dl
RETIC			0-1.5	%
ABS RETIC			<80.000	n x 10 ^{3}/µl
NRBC			0	n/100 wbc
ANISO				
POLYCHR				
HYPOCHR				
POIK				
COMMENT				
WBC		10.100	6.000-17.000	n x 10 ^{3}/µl
SEG	49 %	4.949	3.000-11.400	n x 10 ^{3}/µl
BAND	0 %	0.000	0-0.300	n x 10 ^{3}/µl
LYMPH	43 %	4.343	1.000-4.800	n x 10 ^{3}/µl
MONO	2 %	0.202	0.150-1.350	n x 10 ^{3}/µl
EOS	6 %	0.606	0.100-0.750	n x 10 ^{3}/µl
BASO		0.000	rare	n x 10 ^{3}/µl
META		0.000		n x 10 ^{3}/µl
MYEL		0.000		n x 10 ^{3}/µl
OTHER		0.000		n x 10 ^{3}/µl
PLATELETS		440	200-900	n x 10 ^{3}/µl
PLT EST		adequate		
PP		8.8	6.0-7.5	g/dl
WBC MORPH				

URINALYSIS (Cystocentesis)

COLOR	straw	SEDIMENT	
TRANSPARENCY	clear	RBC/HPF	neg
SPECIFIC GRAVITY	1.021	WBC/HPF	0-2
pH	6.0	CASTS/LPF	neg
PROTEIN	neg		
GLUCOSE	neg	EPI CELLS/HPF	occasional transitional
KETONES	neg	CRYSTALS	amorphous
BILIRUBIN	neg		
UROBILINOGEN EU/dl	normal	BACTERIA	neg
OCCULT BLOOD	neg	MISC	

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Figure 5: Final Exam Excerpt (continued)

CHEMISTRY ☐ SERUM ☒ PLASMA

Specimen Comments

Test name	Results	Ref interval	Units
TOTAL PROTEIN	8.9	5.3-7.8	g/dl
ALBUMIN	4.4	2.3-4.3	g/dl
GLOBULIN	4.5	2.7-4.4	g/dl
UREA NITROGEN	79	5-28	mg/dl
CREATININE	3.1	<1.5	mg/dl
TOTAL BILIRUBIN	0.5	0.1-0.6	mg/dl
ALANINE AMINOTRANSFERASE	83	4-66	mU/ml
PHOSPHORUS	5.5	2.5-5.0	mg/dl
GLUCOSE	70	71-115	mg/dl
ALKALINE PHOSPHATASE	33	<88	mU/ml
SODIUM	130	145-155	mEq/l
CHLORIDE	97	112-124	mEq/l
POTASSIUM	6.1	2.7-5.0	mEq/l
TOTAL CO2	10	13-29	mEq/l
ANION GAP	29.1	10-25	mEq/l
BLOOD GASSES (arterial)			
negative log of hydrogen ion concentration	7.21	7.36-7.44	
Partial pressure of carbon dioxide	29	38-42	mmHg
BASE EXCESS	-15	-2.0 - 2.0	mEq/l
BICARBONATE	12.5	17-24	mEq/l
ENDOCRINE TESTING			
RESTING CORTISOL	0.1	0.5-4.0	µg/dl
POST-ACTH CORTISOL	0.1	8-20	µg/dl

1. Which mechanism best explains the hyponatremia in this case?
   Choose the **correct** answer for 1 point.

a. The dog is sequestering sodium excessively in the peritoneal cavity
b. Diabetes mellitus is causing shift of intracellular water and dilution of extracellular sodium
c. The dog is losing sodium excessively in the urine.
d. An academia is causing extracellular sodium to shift into the intracellular compartment

2. Choose the **most likely** cause for the plasma glucose alteration for 1 point.

a. The hypoglycemia is due to chronic liver failure
b. The hypoglycemia is due to hypocortisolism
c. The hypoglycemia is due to insulinoma
d. The hypoglycemia is due to hypoaldosteronism

3. Choose the **correct** reason for the hyperkalemia for 1 point.

a. The hypochloridemia is causing a false hyperkalemia due to an analytical error
b. The animal is unable to excrete potassium into the distal nephron urine appropriately
c. Anorexia is causing the animal to retain extracellular potassium
d. The diarrhea is causing extracellular potassium to shift intracellularly

Figure 5: Final Exam Excerpt (continued)

4. Choose the **incorrect** answer regarding the acid-base abnormality for 1 point.

a. The dog most likely has a titration metabolic acidosis due to excessive lactate production.
b. The dog has a titration metabolic acidosis as indicated by the increased anion gap
c. The data shows a respiratory acidosis that is most likely a primary acid base disturbance
d. The data shows a decreased TCO_2 which is an estimate of decreased plasma bicarbonate.

5. Choose the **incorrect** explanation for the urine specific gravity for 1 point.

a. The urine specific gravity is a normal finding (consistent with health) in this patient
b. The urine specific gravity implies renal medullary washout (decreased renal medullary osmolality) in this patient.
c. The animal has a decreased capacity to reabsorb sodium from the renal tubular filtrate
d. Your patient’s kidneys have a decreased capacity to concentrate urine

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