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ABSTRACT

Concept maps have been used successfully in science and mathematics education in a variety of settings. This paper describes the application of the metacognitive tool, concept mapping, to the development of an integrated veterinary curriculum, to the development of case-based exercises for problem-based learning, and as a learning tool for students working individually or in small groups. Examples are drawn from courses developed for a new veterinary curriculum implemented in 1993. Special attention is paid to a course taught to 65 veterinary students in the spring of 1995 on fluid and electrolyte disorders. Concept maps were integral to the design and delivery of the course, and were included in the final examination. The use of concept maps to this extent was well received by students. The vast majority claimed that the concept maps greatly facilitated their understanding of the relevant pathophysiologic mechanisms contributing to an acid/base disturbance or fluid disorder. Responses from the faculty involved with the course were also very positive. It is argued that concept maps can help make conceptual relationships explicit, identify errors and omissions, and reveal misconceptions in students' understanding. (Contains 1 table, 6 figures, and 40 references.) (Author/SLD)

AERA Symposium: Alternative Approaches to Research on the Cognitive Structure of Concepts

Concept Mapping to Facilitate Veterinary Students' Understanding of Fluid and Electrolyte Disorders

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Abstract

This paper addresses efforts to facilitate the quality of veterinary medical students' understanding of fluid and electrolyte disorders through the use of metacognitive tools, specifically concept maps. Concept maps have been used successfully in science and mathematics education in a variety of settings. The paper describes successful application of concept mapping to the development of an integrated, interdisciplinary veterinary curriculum, the development of case-based exercises for problem-based learning, and as a learning tool by students, working individually or in small groups. Examples are drawn from courses developed for a new veterinary curriculum (implemented in the fall of 1993); special attention is paid to a course taught to 65 veterinary students during the spring of 1995 on fluid and electrolyte disorders. Concept maps were integral to the design and delivery of the course, and were included in the final examination. The use of concept maps to this extent was well received by students; the vast majority claimed that concept maps greatly facilitated their understanding of the relevant pathophysiologic mechanisms contributing to an acid/base disturbance or fluid disorder. Responses from the faculty involved with the course were also very positive. The authors argue for the need to help students integrate their learning, and for the value of concept maps in helping to make conceptual relationships explicit, in identifying errors and omissions, and to reveal misconceptions in students' understanding.

Introduction and Background

Educators for many years in many disciplines have wrestled with the challenge of improving the quality of students' learning. David Ausubel (1978) posed an enormous challenge to teachers when he stated: "The most important single factor influencing learning is what the learner already knows. Ascertain this, and teach him accordingly." (Ausubel, Novak, & Hanesian, 1978) Deceivingly simple, this directive requires teachers to consider the student's prior knowledge as the foundation for new learning, and poses questions not only of what knowledge the student currently holds, but also of its structure. How is knowledge in one's long-term memory stored? How might one's cognitive structure influence subsequent learning? What role might errors, omissions, or misconceptions (also held as prior knowledge) play in the quality of learning that follows? How might these be corrected? How does knowledge change? Are old concepts replaced by new ones through a process of substitution, or does knowledge "grow" in some way? Ausubel's statement also raises questions about how best to "ascertain what the learner already knows." In the world of the classroom, these challenges are complex and imposing.

Largely due to the influential work of Jean Piaget, theories of cognitive psychology and the view that learners construct knowledge has gained acceptance in the latter half of this century. Contemporary epistemological theories also emphasize the central role of the knower in structuring knowledge (von Glasersfeld, 1995); (Watzlawick, 1984); (Tobin, 1993). Constructivism has been derived from both philosophy and psychology (Knorr-Cetina, 1983); (Fabricius, 1983);

(Novak, 1987a), although many applications of constructivism to education appear in the science and mathematics literature. As a theoretical foundation, constructivist views have led to a number of fruitful areas of research on human learning. The research base continues to grow; topics of investigation relevant to the present study include: students' misconceptions or alternative frameworks (Driver, 1983); (Helm & Novak, 1983); (Novak, 1987b); (Wandersee, Mintzes, & Novak, 1994) mechanisms for conceptual change (Posner, Strike, Hewson, & Gertzog, 1982); (West & Pines, 1985); differences in the knowledge structures of experts and novices (Chi, Feltovich, & Glaser, 1981); (Olson & Biolsi, 1991); (Perkins & Salomon, 1989); and applications of assimilation learning theory involving heuristics and other metacognitive tools (Novak & Gowin, 1984); (Novak, 1990b); (Roth, 1993).

Questions related to the ways in which learners structure information have significance beyond portraying a more accurate description of knowledge acquisition. The retention of knowledge, and how it is applied in new situations, are of fundamental importance for education, and the view that cognitive structure and long-term memory are strongly related is currently widely accepted among cognitive psychologists and educators. From the standpoint of educating, the goal of any educative event is shared meaning between teacher and student (Gowin, 1980). Shared meaning leads to meaningful learning, which is a process that builds upon prior knowledge, and carries with it the learner's conscious attempt to integrate new information with what he or she already knows. In contrast, and at the other end of a learning continuum, is rote learning. In situations in which material is learned by rote, no attempt is made by the learner to assimilate new information into an existing framework, and the material is often quickly forgotten (Novak, 1977). Even in cases where students perform well within the context of an isolated course, they may not be learning in such a way that results in an integrated understanding of related concepts across courses. As Coles (1990a) states:

> Students need to be encouraged to recognize that merely understanding what they are learning (deep-processing) is not in itself sufficient. They need to elaborate their knowledge; to build up more and more complex networks; to 'structure' their knowledge . . . It is also important that students make connections between courses.. . . Students need to see that all their courses are related in some way . . . and to see that their task is largely one of seeking out and establishing those links. (pp. 305, 6)

Educational researchers have taken numerous approaches to representing learners' cognitive frameworks. Many of these methods have included some form of graphical depiction (Johnson, Goldsmith, & Teague, 1995); (McKeachie, Pintrich, Lin, & Sharma, 1990); (Olson & Biolsi, 1991). One assumption these different approaches hold in common is that by understanding the ways in which students structure what they learn, teachers will be better able to tailor their teaching approaches to achieve their educational goals. Another commonality is the notion that tangible artifacts of learning help teachers (and learners) to correct common errors or misconceptions. Concept maps and Vee diagrams (Novak & Gowin, 1984) have also been used as "road maps" for learning, to communicate to students how new learning will build upon their previous knowledge. Devices such as repertory grids have been used to illustrate the ways in which students structure knowledge, comparing students' grids to those of their teachers in order to enhance understanding (Bezzi, 1996); (Murphy & Friedman, 1996).

All of the research cited above and that described by the other presenters in this symposium is oriented toward helping students learn more effectively. In most cases, the goals of instruction exceed content mastery; not only do teachers want their students to learn, they want them to learn *better*. In medicine, the problem of helping students to integrate their learning is as real as it is in other disciplines, but the stakes are very high; errors in clinical practice come with a very high price. Entwistle (1992) reiterated the need for medical students to employ meaningful learning strategies:

> . . . deep, elaborated methods of studying medicine seem to require the student to develop a structure of understanding which links scientific conceptual understanding to cases, within a clinical context.. . . In medicine, it seems that many students may be trying to operate with opposing structures-- those which follow the logic of the discipline and those which make sense of clinical experience-- without a clear idea of how to integrate them. (p. 603)

Medical educators have been interested primarily in the development of problem solving skills, especially as they relate to the development of expertise and the diagnostic reasoning process (Bordage & Zacks, 1984); (Boshuizen & Schmidt, 1990); (Patel, Kaufman, & Magder, 1991); (Patel & Groen, 1986);(Schmidt, Norman, & Boshuizen, 1990). Accuracy in diagnosis is crucial to the effective practice of medicine, and much of the research on developing medical expertise builds upon the educational principles outlined above. Within the context of the professions, the ability to draw from an extensive knowledge base and apply it to a real world situation is critical to success. Teachers, doctors, lawyers, architects, business executives and other professionals must be able to blend theory with practice; it is not only the experts' extensive knowledge and experience in a field that makes them valuable, it is their ability to make judgments and to act, based upon that knowledge.

This paper will report on efforts to facilitate meaningful learning within the context of veterinary medical education. Examples will be drawn from courses developed for an integrated, multidisciplinary veterinary curriculum. It will focus particular attention on the problem of helping veterinary medical students to develop elaborated understandings of fluid and electrolyte disorders through the use of metacognitive tools, specifically concept maps.

Concept Mapping and Meaningful Learning

Concept mapping is a tool for representing the interrelationships between concepts in an integrated, hierarchical manner. Concept maps depict the structure of knowledge in propositional statements that dictate the relationships among the concepts in a map. Connected by labeled lines, the concepts depicted in concept maps have superordinate-subordinate relationships as well as interrelationships. Based upon assimilation theory (Ausubel, et al., 1978), concept maps facilitate meaningful learning by making conceptual relationships explicit, and by serving as advance organizers to subsequent learning. Like knowledge itself, concept maps are context-dependent. Different maps containing the same concepts may convey very different meanings depending upon the relative emphasis and arrangement of individual concepts. This feature makes concept mapping particularly helpful for illustrating the ways in which context influences both what we know and how we use what we know. It allows knowledge to be portrayed as dynamic and subject to change, and illustrates the integrated nature of understanding.

As heuristic devices, concept maps make the structure of knowledge explicit to students and they reveal to teachers the idiosyncrasies in students' cognitive structures due to prior knowledge and experiences. They also reveal students' errors and omissions, and alternative frameworks. Concept maps have been used successfully in many disciplines, particularly in science (Heinze-Fry & Novak, 1990); (Novak, 1990a); (Novak, Gowin, & Johansen, 1983); (Starr & Krajcik, 1990); (Willerman & Mac Harg, 1991) to promote meaningful learning and effective teaching. Concept maps may be used by students as a study tool, or by teachers to evaluate learning, to enhance teaching, or to facilitate curriculum planning. Concept maps have been particularly helpful in identifying and illustrating qualitative aspects of students' learning. Applicable to any discipline at any level, they are metacognitive tools that can help both teachers and students to better understand *the content and process* of effective, meaningful learning.

Concept Mapping in Veterinary Education

Concept maps have been used extensively by members of the faculty at the College of Veterinary Medicine at Cornell University to develop a new professional curriculum that was implemented in the fall of 1993. Structured deliberately to emphasize certain conceptual themes and interrelationships, faculty planners created concept maps representing the curriculum as a whole, each of the major courses, and all of the case-based exercises used in the first four of six sequentially scheduled Foundation courses (Edmondson, 1995). Courses in the first two years of the curriculum are taught predominantly with problem-based methods, and these are the courses for which concept maps have been used. Some laboratory exercises and lectures have also been planned by faculty with the aid of concept maps, allowing interdisciplinary groups of faculty planners to trace common themes and concepts without regard to disciplinary boundaries. Because concept maps are visual and concise, they have been useful for communicating large amounts of information efficiently, and they help to remind faculty tutors of the areas of major emphasis important to the investigation of individual case-based exercises.

Concept maps have been instrumental in helping the veterinary faculty to reconceptualize their subject matter, as they moved beyond disciplinary boundaries in developing new courses. Each concept map serves as a kind of road map, guiding case writing (Edmondson, 1994) by illustrating areas of redundancy and omission, and reassuring faculty about content coverage and curricular coherence. Rather than summarizing the curriculum through a series of outlines or course syllabi, the concept maps illustrate the dynamic network of conceptual relationships and emphasize important themes. This framework for curriculum development offers the flexibility to guide the development of future courses as well as anchoring the evolving interplay of course revisions that characterize a dynamic curriculum.

Traditional medical curricula do not allow faculty to shape the teaching and learning process to this degree, because the emphasis is on didactic teaching, not meaningful learning. In most medical curricula, many faculty teach for discrete periods of time within lengthy courses that are organized by discipline. By shifting their focus to students' learning, faculty find their roles to be more enjoyable, rewarding, and intellectually stimulating. Concept maps help the faculty to focus on the quality of their students' learning, thereby making the purpose of their actions clear, and encouraging the students to construct an integrated conceptual framework that will inform their professional practice.

The concept maps representing each of the Foundation courses of the veterinary curriculum are given to all faculty and students participating in a course, and they are posted in all tutorial rooms. In addition, many faculty tutors encourage students in their tutorial groups to develop concept maps to summarize their understanding of the key concepts and principles fundamental to a case. Individual students create concept maps as aids to studying, and occasionally small groups of students collaborate to create maps when they prepare for examinations. Students sometimes share the concept maps they have created with others in their tutorial groups for discussion and clarification. More often, faculty tutors will ask their groups to generate a concept map illustrating the relations among important concepts raise by the case.

Figure 1 illustrates a concept map created by a group of six first-year students at the conclusion of a week-long investigation of a case of laryngeal hemiplegia in a horse. The case is third in a sequence of eleven comprising a course entitled "The Animal Body," which includes the subject areas of gross and microscopical anatomy, radiology and imaging, and approaches to surgery. Given that the students who created this map had been in veterinary college for less than one month, their summary of the case is impressive. It took them about thirty minutes to construct, and allowed the group to review the main anatomical and neurological concepts they had learned, in addition to the clinical dimensions of presenting signs and course of treatment (in this case, surgical correction). Although the process of creating the concept map allowed the group to reinforce and summarize what they had learned, it also reminded them of areas they still needed to pursue, and of questions (such as whether the hyoid apparatus contains bones) they needed to resolve.

[Insert Figure 1 about here.]

At the College of Veterinary Medicine, faculty who have become comfortable with creating concept maps for the larger interdisciplinary Foundation courses are also beginning to apply them to shorter courses they design and teach individually. The power of concept maps in succinctly communicating multiple dimensions of a given topic allows faculty to capture these elements in their teaching in ways traditional approaches to curriculum planning have not allowed. Used as teaching tools, faculty are able to express conceptual relationships more clearly, and as reflections of student learning, faculty are better able to determine whether or not students have understood. This approach has been particularly fruitful for those faculty who have applied concept mapping to facilitate their presentations of issues that are widely recognized as being difficult for students to understand.

Because the academic program is interdisciplinary, faculty have the opportunity (and are encouraged) to offer courses addressing important issues in medicine that require students to integrate their understanding of fundamental

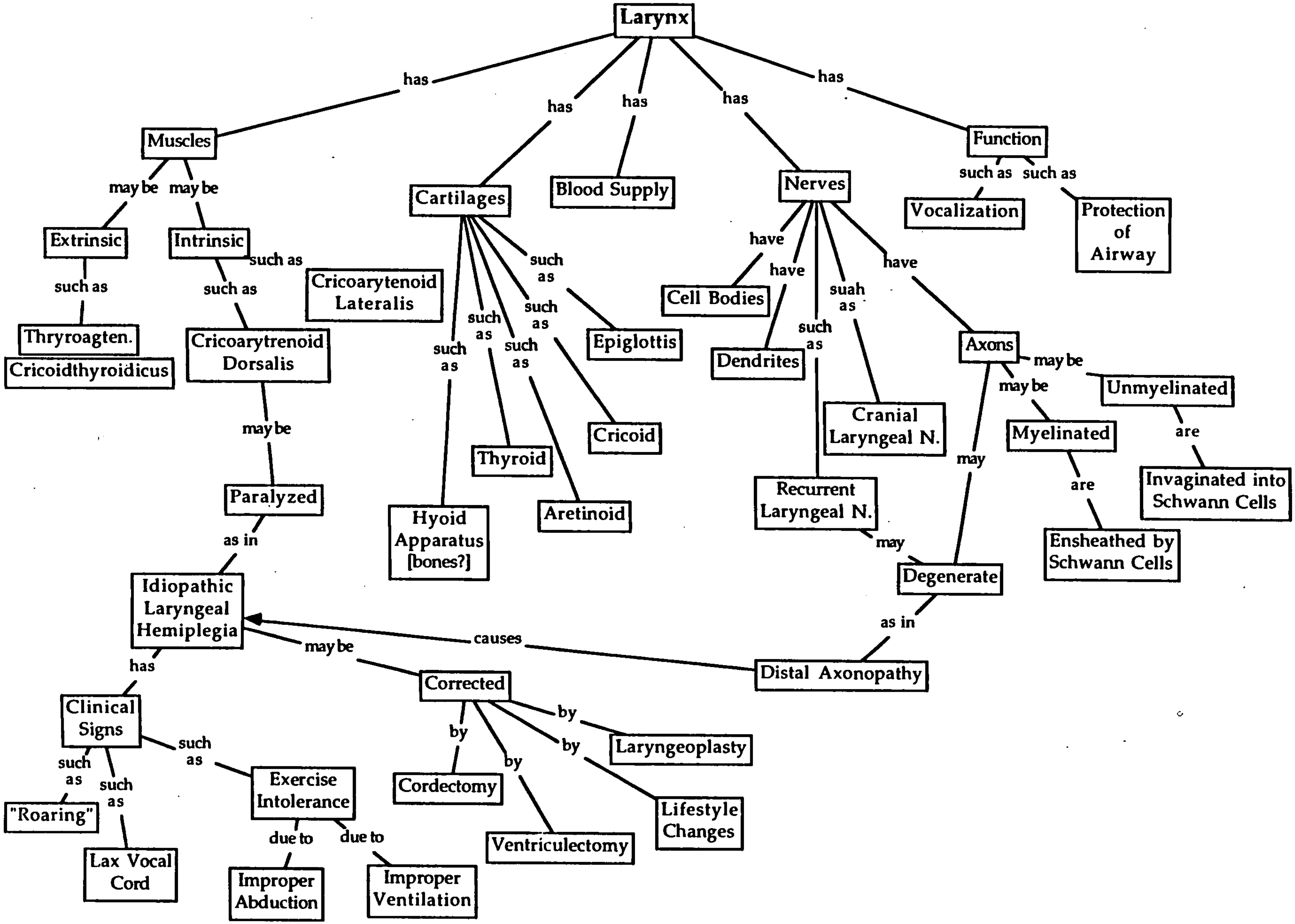

Figure 1: Concept map created by students in a tutorial group to summarize and synthesize their understanding of a case.

physiological and pathophysiological mechanisms with clinical applications and principles of therapy. The curricular structure now allows shorter courses devoted to special topics to be taught during a discrete period of time, employing a range of teaching styles. These courses occupy an eight-week period during the spring semester for all four years of the curriculum, allowing some flexibility of choice and encouraging students to pursue many aspects of their biomedical or clinical knowledge in greater depth. It is within this eight-week period that VM 642, "Management of Fluid and Electrolyte Disorders," is taught. Our focus will now turn to a more detailed discussion of this course, with an emphasis on the role concept maps have played in student learning and in the delivery of the course.

The VM 642 Course: "Management of Fluid and Electrolyte Disorders"

Management of fluid and electrolyte disorders and a comprehensive understanding of acid-base balance have historically been very difficult areas for veterinary students to grasp. For years, our faculty in both the basic and clinical sciences struggled with how best to present material that is complex and requires an understanding of several interrelated physiological mechanisms, applied to clinical situations. In the current veterinary curriculum, these issues emerge through several case-based exercises, and all aspects are considered within the context of a clinical scenario. However, the main emphasis of the case discussions is the nature of underlying mechanisms, and fluid and electrolyte therapy as a clinical subject is not addressed in depth.

The eight-week, VM 642 course was developed to address a need to help students understand the principles for managing fluid and electrolyte disorders with a discussion of the underlying mechanisms. It requires students to solve clinical problems relating to fluid and electrolyte disorders while emphasizing the pathophysiological basis for fluid compartment and solute abnormalities. As a prerequisite, all students must have completed the first three semesters of the veterinary curriculum. The course builds upon the principles of fluid, electrolyte, and acid-base physiology previously learned as integral parts of the problem-based case exercises, and it challenges students to apply their understanding of basic science mechanisms to a variety of clinical situations.

Taught for the first time during the spring of 1995, the course has three principal educational objectives. It is intended to help students:

1. To recognize and understand the clinical manifestations of the major fluid and electrolyte disorders common to domestic animals.

2. To become familiar with the basic pathophysiologic principles underlying these problems.

3. To understand the basis for medical treatment of these disorders, with emphasis on fluid and electrolyte therapy, and correction of acid-base abnormalities.

During the first class meeting, students were asked to complete a "pre-test" that would help the instructor (DFS) to learn more about their previous collective experience with management of fluid and electrolyte disorders and to give him an idea of their understanding of concepts related to acid-base balance. The pre-test was not scored, and after students completed them, there was a general class discussion of their responses. So, for example, after they had responded to a series of questions regarding their use of fluids: "Have you administered fluids?; Have you seen them being used?; Did you understand why they were used?", they were asked to indicate their responses by a show of hands. This was done so that they better understood as a class the level of their prior knowledge and experience. In fact, the entire exercise was intended to activate their relevant prior knowledge and to accomplish the latter goal, and not to provide more than a rough measure of any baseline knowledge. It also helped to establish the overall tone of the course; students were expected to participate often in the discussions and were encouraged to consult their peers and draw them into the exchange.

To further encourage student involvement and to foster a collegial atmosphere in the classroom, the instructor used one-minute paper writing exercises each week to elicit ongoing student feedback about the course. Students were asked to indicate the most important thing they had learned in class that day, to list any questions that remained in their minds following discussion, and for any suggestions they had to improve the course. Response to these questions was voluntary but generally very high. Students' comments were thoughtful, and, when taken together, helped to identify common trends. The students were also warned that they would be asked to complete a post-test at some point following the course, though their participation would be voluntary. In no way was their performance on either the pre-test or the post-test calculated as part of their final grade for the course.

The instructor wanted to foster active student learning and discussion, as well as to continue the emphasis on learning in context that problem-based methods create. Due to a large enrollment (62 students in 1995; 84 in 1996), VM 642 was divided into two sections, each of which met twice per week. Mini-lectures and large group discussions were the predominant teaching modality. On Mondays, topics for each week were introduced in a one-hour interactive lecture based on concept maps; students also received problem sets to complete before the two-hour discussion held the following Thursday.

A typical problem set presented the students with a series of clinical scenarios describing an initial presentation of an animal, its physical examination findings, and possibly some laboratory data. A number of questions followed, requiring students to review or learn the pathophysiologic basis for the disease condition, to interpret the initial data, predict whether concentrations of important solutes would be increased or decreased, explain their rationale, and develop a rational basis for treatment. Students were also expected to account for any acid-base disturbances, and justify their proposed choice of fluid therapy.

The students used two heuristics to help them solve these problems: a "three-column technique," and concept maps. Both heuristics were integral to the delivery of the course; concept maps were integral to its design. The "three-column technique" required students to identify the primary problems (e.g. volume depletion, high anion gap metabolic acidosis), develop a rationale for treatment (e.g. volume expansion, alkalinizing solution, potassium supplementation), and a choice of fluid therapy to correct the disorder (e.g. lactated Ringer's Solution with potassium chloride added). Concept maps were used by the course instructor to introduce new concepts, to illustrate the interrelationships among the key concepts in the course, and as a tool for guiding and organizing class discussions. As discussion progressed, the instructor added concepts to a map he created in class. By eliciting information from students during discussion, he built a framework *with* them that incorporated multiple dimensions of each of the problems.

Students were asked to construct concept maps of their own at two points during the course: at around the mid-way point, and at the end, as part of the final examination. In the spring of 1996, students who had enrolled in the 1995 course offering were also asked to create a concept map as part of the post-test administered one year after completing the course (described below). In 1995, all 62 students enrolled in the course were in their second year of study. All were familiar with concept mapping to some extent; a small number had attended a concept mapping workshop in addition to constructing concept maps in tutorial sessions. The construction of concept maps during the class discussions provided students with additional experience with the technique.

During the Monday sessions, the instructor began with a short presentation about a pathophysiologic issue such as hypokalemia. Presented as a concept map, he wrote "hypokalemia" on the board and elicited a discussion that elaborated the issue, thereby identifying other important concepts. These were added to the concept map as the discussion progressed. An example of a concept map used as the basis for a mini-lecture is shown in Figure 2.

[Insert Figure 2 about here.]

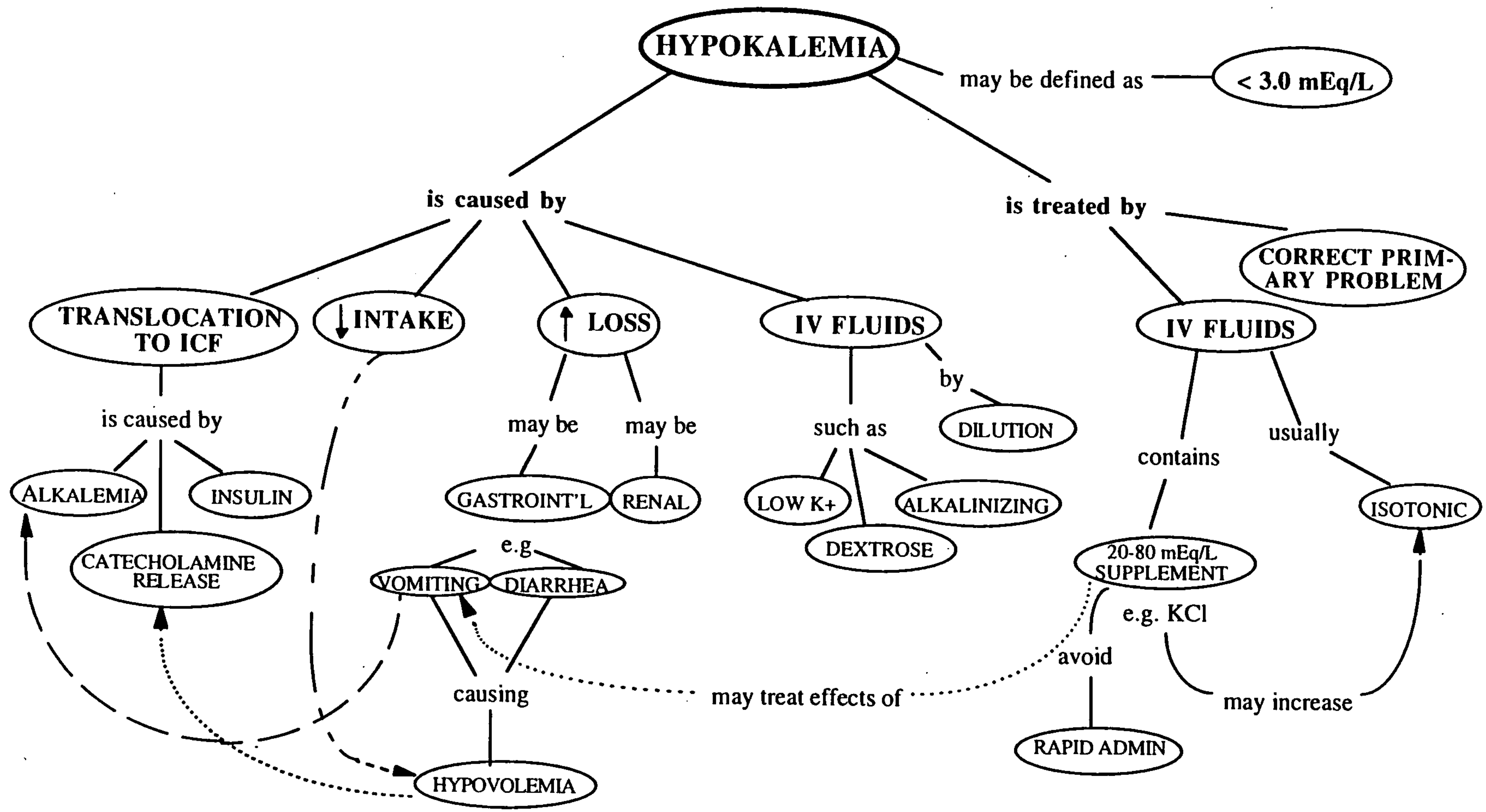

Figure 2: Concept map of hypokalemia created by the course instructor to guide a lecture.

The two-hour class sessions met on Thursdays. They began with a summary of one of the case presentations from the assigned problem set, and students were asked to identify the important clinical signs and the most important metabolic disturbance. Again, the instructor constructed a concept map with the class, this time with either the diagnosis or the presenting complaint (such as a dog with gastric dilitation-volvulus) as the superordinate concept. Together, they constructed a map that not only summarized the case presented in the problem, but that also illustrated key conceptual relationships fundamental to developing a rationale for treatment. An example of a concept map created in such a discussion is shown in Figure 3. The instructor would then ask the class to proceed through the "three-column technique," drawing columns on the board that categorized presenting signs, the goals for treatment, and a choice of therapy.

[Insert Figure 3 about here.]

By illustrating the ways in which key principles related to pathophysiological mechanisms, students in VM 642 learned that depending upon the situation, certain choices for fluid therapy are more desirable than others, but not necessarily wrong. There was often more than one "right" answer. It is this aspect of clinical practice that can be problematic for students to accept, and their discomfort with their inability to justify a choice for treatment can lead to rote memorization: In situation A, use fluid X; in situation B, use fluid Y. (A similar analogy can be drawn to the task of prescribing medications.)

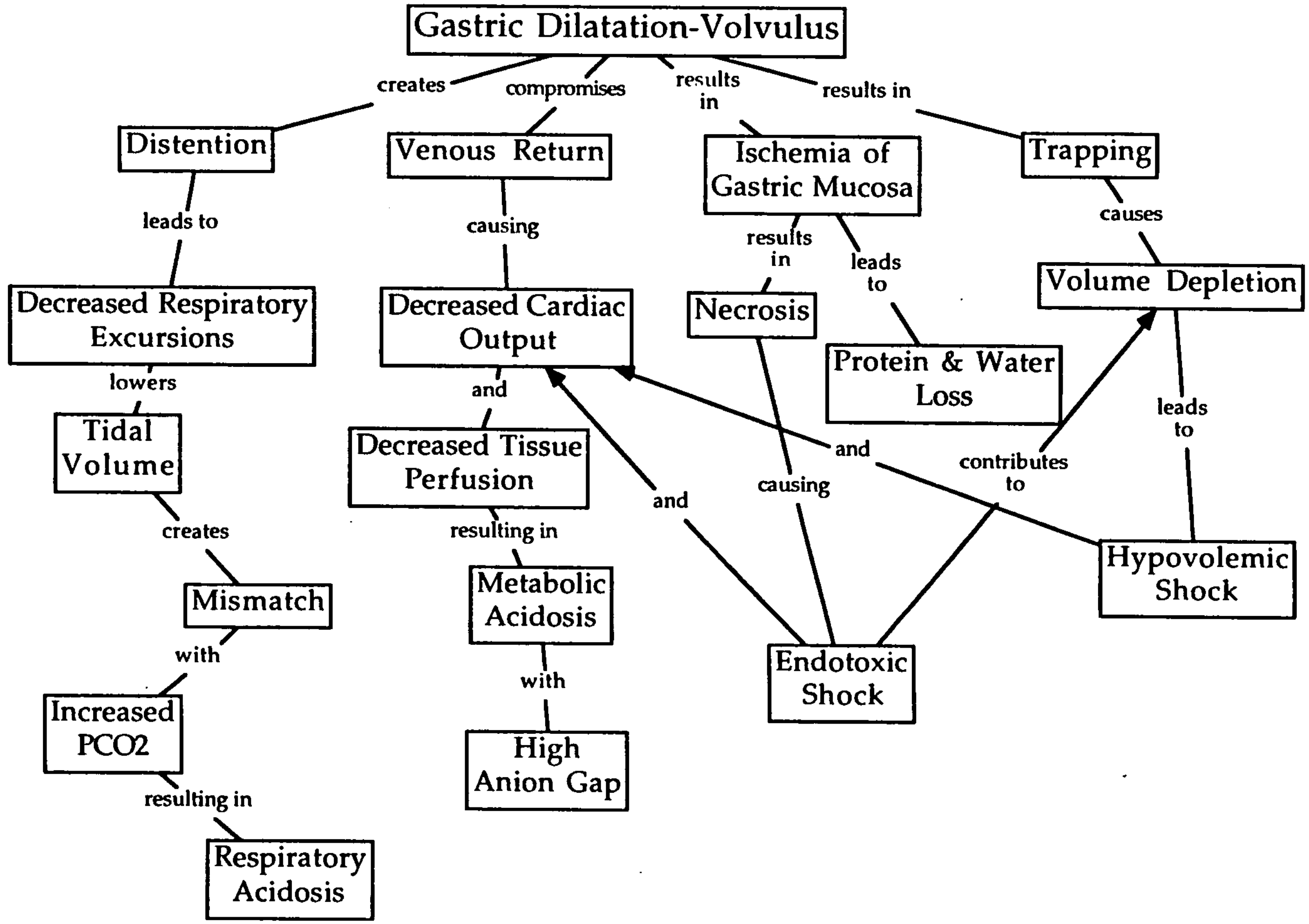

Figure 3: Concept map of gastric dilatation-volvulus created during class discussion.

By highlighting the relationships between physiological mechanisms and clinical and laboratory presentation, the problem sets helped students to develop clear rationales that support their choice for treatment. The class would then discuss their various choices, weighing the advantages and disadvantages of each. By the end of the session, the students would have identified the courses of treatment that are more preferable than others, but they were also able to support that judgment on the basis of their pathophysiologic rationale. The rationale underlying treatment represents the synthesis of their pathophysiologic and clinical knowledge. Both of the heuristics used in this course help students to achieve this goal, but the concept maps help to isolate the primary disturbances the rationales for treatment are intended to correct.

The format of the final examination was consistent with the students' learning experience in the course; it consisted of two clinical scenarios, completed during a three-hour period. The first problem required students to evaluate data from an initial physical examination and clinicopathological tests, to characterize the animal's fluid, electrolyte, and acid-base status, perform some calculations, and to construct a concept map depicting the principle pathophysiologic events in the case. Students were also expected to choose a course of fluid therapy (complete with volume and rate of administration), stating the major considerations they hoped to address and justifying their rationale. The scenario continued as the animal received surgical treatment; students were also required to state how they would manage secondary problems that occurred after resolution of the initial problem.

The second case scenario asked students to infer some information about a clinical presentation they encountered after the choice of therapy had been made. It presented students with an animal that had been placed on fluid therapy (the specific fluid and rate of administration were specified) and asked students to use the information provided about the history and clinical signs to present a cohesive picture of what the hematologic, electrolyte, and acid-base parameters *might have been* upon the animal's admission to the clinic prior to treatment. They were then asked to comment on the appropriateness of the fluid being used, justifying their reasoning on the basis of their assumptions.

In the spring of 1996, one year after the first class of students completed the VM 642 course, the course instructor administered a post-test to evaluate students' retention. The format of the post-test was very similar to the problem sets used in the course. Students were asked to list clinical and pathophysiological abnormalities they would expect in various clinical scenarios, then to describe how they would treat the animal; to list the most significant concepts related to two clinical scenarios, indicating the three most important concepts; and to create a concept map describing the pathophysiological changes they would expect to see in a horse with ascending colon volvulus. For the latter task, students were given a list of ten concepts to incorporate into their maps, and were asked to add at least five additional concepts. The entire assignment was to be completed in less than an hour; no reference materials were to be used.

Results and Educational Outcomes

The extensive use of concept maps in this course was well received by students; the vast majority claimed that concept maps greatly facilitated their understanding of the relevant pathophysiologic mechanisms contributing to an acid-base disturbance or fluid disorder. Occasionally during the course, students made comments in their weekly one-minute papers about the value of concept maps for their learning. In the third week, one student wrote: "Use concept maps more often-- today's was very helpful." The following week, another wrote: "I like the concept map prior to the case-- it helps to understand it better." And another noted: "I love when you introduce issues with concept maps-- good session today."

At its conclusion, students were asked to evaluate the course, rating a number of aspects (e.g. clarity of objectives, pacing, educational format, final examination, etc.) on a five-point Likert scale. They were also asked to write additional comments to specific questions that focused on the use of concept maps and the three-column technique. Forty-nine of the sixty-two students (79%) enrolled in the course completed the course evaluation. A summary of the tabulated results is presented in Table 1.

[Insert Table 1 about here.]

Although just under half (47%) of the class agreed or strongly agreed that the assignment asking them to create a concept map about intravenous fluids during the course was an effective learning device, 78% of the students who completed the

Table 1: Summary of Students' Responses to the Course Evaluation

Item	1	2	3	4	5	% rating 4 or 5
Did the course provide an intellectually stimulating environment?	0	0	3	32	14	*94*
How well did the course instructors facilitate the integration of basic and clinical sciences?	0	0	4	21	24	*92*
How well did the course build upon concepts learned previously in the curriculum?	0	0	7	25	17	*86*
How well do you think the course has prepared you for future courses and for your clinical experiences?	0	0	4	20	24	*92*
Did the use of the three-column technique during the Thursday sessions facilitate your learning?	0	3	2	16	27	*90*
Did the use of concept maps during the Thursday sessions facilitate your understanding of relevant pathophysiological mechanisms?	1	1	9	21	17	*78*
Was the creation of the concept map of intravenous fluids, assigned during Week 6, an effective learning device for you?	1	8	17	12	11	*47*
Would more formal instruction in developing concept maps have been helpful, considering the emphasis placed on concept mapping during the course?	13	8	13	11	4	*31*

1 = Never, very poorly
2 = Occasionally
3 = Sometimes, reasonably well
4 = Often
5 = Always, very well

course evaluation either agreed or agreed strongly with the statement that the use of concept maps facilitated their understanding of relevant pathophysiologic mechanisms. These ratings were accompanied by responses to the following request: "Please explain how the use of concept maps during the Thursday sessions affected your learning (either positively or negatively); give specific examples if possible." Students' responses elaborated their positive ratings, as evidenced by the following comments:

> The concept maps helped me extremely. After going through them over and over, I became able to put my thoughts down on paper for any question. It also organized my knowledge so I could see what I knew and where I was lacking information.

> I am usually not a "concept map person" and I found them extremely helpful in tying together important points and clinical signs. By doing them as a class, I learned how to do them better on my own.

> I, honestly, do not care for concept maps because they can get confusing and cumbersome. Some we did in class were helpful. I was, however, very surprised that I was able to construct a decent concept map of my own on the [final] exam. I guess they were beneficial in the end.

> I didn't think they did until I got to the exam and that concept map came really easily. They helped me to connect concepts with each other as well as with specific treatment protocols.

> I eventually drew concept maps to study for each case.

> I like concept maps. For me, they organize a complex physiologic mechanism and I find I retain the information because is it organized, logical, and not just random facts.

Students also rated the use of the three-column technique very highly, and elaborated in their responses to the question: "Did the use of the three-column technique during the Thursday sessions *(problems; rationale for fluid therapy; specific fluids to use)* facilitate your learning?" The value of this systematic approach to analyzing a clinical situation from its pathogenesis to treatment is evidenced in the following representative comments:

> It helped simplify a potentially complicated presentation by listing each problem and [seeing that] one of the rationales could solve multiple problems. It basically kept me focused.

> This type of thing helps me more than concept maps. Stating the problems as entities then defining the rationale for fluid treatment helped me break it down to a more manageable level.

> I thought it was excellent for organizing one's thinking about the case and visually demonstrating [which] problems were or were not being addressed with the different types of fluids. I really liked this technique!

Some of the students' comments compared the use of the three-column technique to concept mapping:

> Not as useful as the maps because it was something that was simply memorized, but the "rationale" column helped to alleviate this. Was good for quick reference purposes.

> Provided a format for organization, but the issues were so apparent after concept mapping it felt forced.

Given that concept maps played such a central role in the delivery of the course, we were delighted with these responses. It had been clear throughout the course that the students were learning effectively. The quality of the discussions had been consistently high, and feedback on the one-minute papers had frequently confirmed the instructor's impressions. Student performance on the final examination was good; the majority of the students received a grade of A or B, and the instructor felt satisfied that the educational objectives of the course had been met. He also commented that his use of concept maps in the course contributed extensively from the standpoint of his professional growth as a teacher, an added benefit of the experience. In particular, he noted that concept maps helped him to organize and plan for the weekly sessions, and heightened his awareness and understanding of how students learn, especially with regard to their ability to integrate concepts from physiology and medicine.

The primary reason for using concept maps in VM 642 was to facilitate students' understandings. The concept maps students constructed communicated their knowledge and understanding, which in some cases was exemplary. Figures 4 and 5 are examples of such comprehensive, valid understanding. These maps reflect the idiosyncrasies of the map makers, but they are also accurate. They reflect a solid foundation upon which to build subsequent knowledge of medicine-- course material the students had not yet engaged in at the time these maps were created.

[Insert Figures 4 and 5 about here.]

In addition to encouraging synthesis and integration, students' concept maps also provided the course instructor additional insights into common errors or

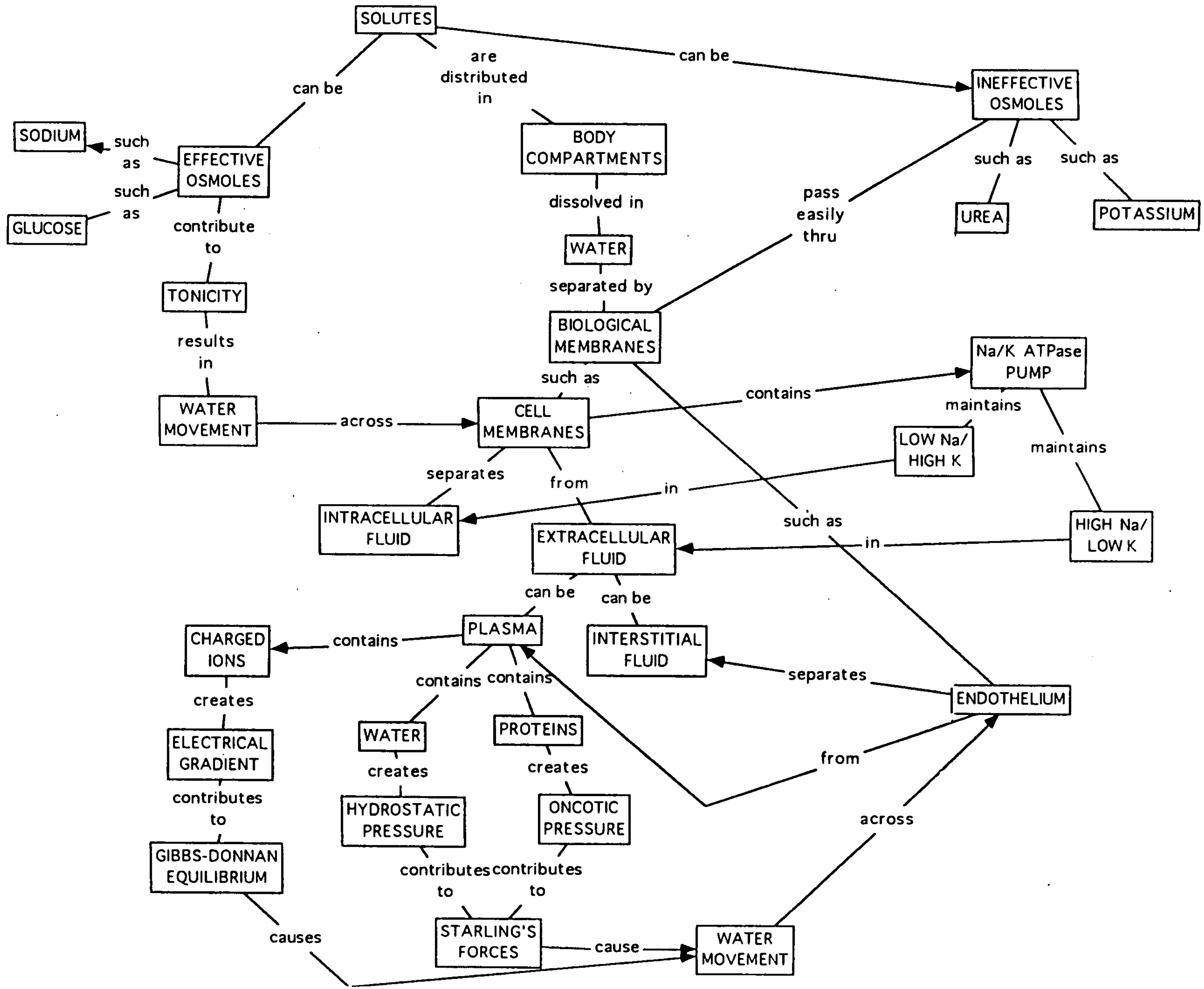

Figure 4: A student's concept map of solutes, constructed during the course, representing comprehensive understanding (relationships are valid, well organized, and integrated).

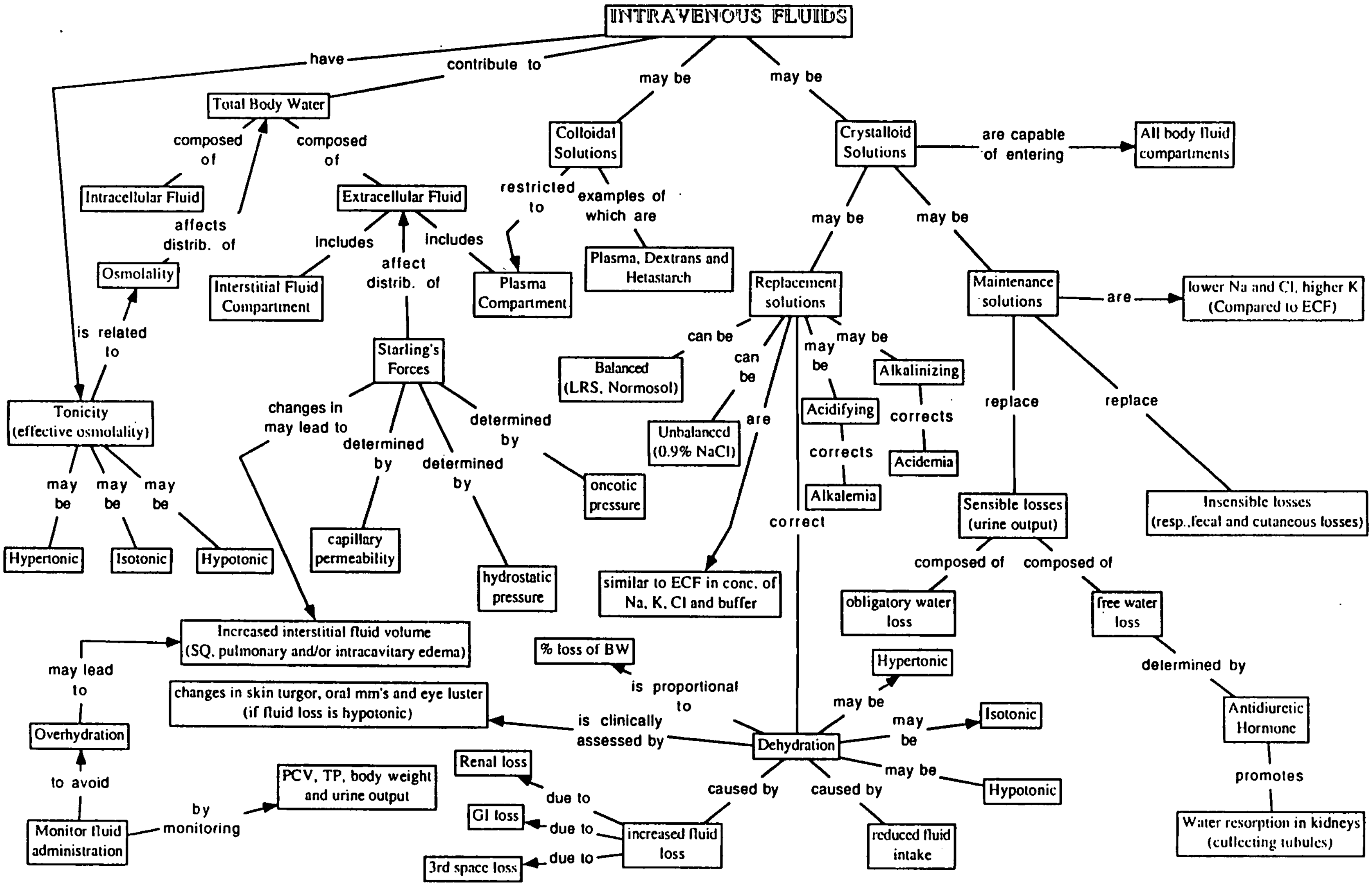

Figure 5: A student's concept map of intravenous fluids, constructed during the course, representing comprehensive understanding (relationships are valid, well organized, and integrated).

misconceptions. Several students consulted with the course instructors during the preparation of their maps, so the process was also useful as a learning tool. In some maps, the majority of the propositional relationships were valid, but the map contained parts that indicated an error or omission. This kind of information was very useful to the instructor in providing feedback to the student who made the map. Errors common to several students provided a signal to the instructor of the need to clarify particular issues during class. Figure 6 presents an example of an error made by several students concerning the relationship between hypobicarbonemia and metabolic acidosis. A small subset of the class drew causal links between them, reflecting a misunderstanding, despite the fact that the other elements in their maps depict valid relationships.

[Insert Figure 6 about here.]

Post-tests were offered a year later to all students who had enrolled in the course. Of the sixty-two students who had taken the course, twenty completed the post-test. In the intervening year, students who had taken VM 642 had been enrolled in a lengthy multidisciplinary course that focused on medicine, surgery and related clinical disciplines, prior to beginning clinical rotations.

The students were asked to treat the post-test as a closed-book exercise, and their performance seemed to reflect good retention of the material. Whether the experiences they had had in the clinical course facilitated this is difficult to determine, but it was clear that the students who completed the post-test had not

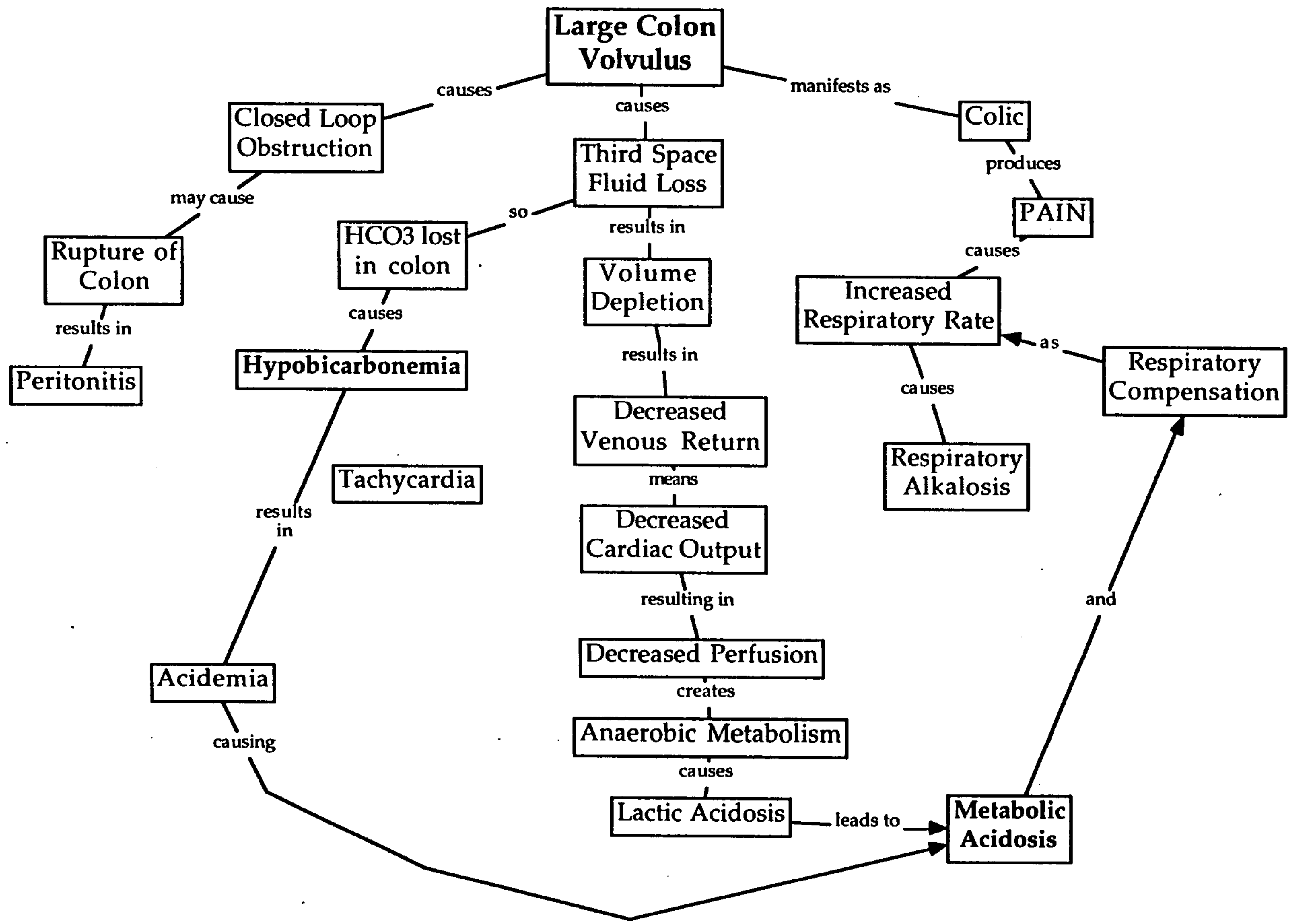

Figure 6: A student's concept map of large colon volvulus, illustrating errors and misconceptions about the relationship between hypobicarbonemia and metabolic acidosis (and between respiratory compensation and increased respiratory rate).

lost their understanding of key concepts and principles as they related to the scenarios presented. Hopefully, their future experiences in the teaching hospital will further reinforce this understanding, allowing students to build upon a scaffold of conceptual relationships they constructed during the course. One student commented:

> I did learn so much from the course and appreciate that. My understanding of renal physiology/pathology, total body water, and the types and uses of fluids increased tremendously, and seems to be a good "working knowledge" (pretty good retention).. . . Due to your course, I feel competent in management of fluid/electrolyte disorders although I have to work on remembering specific numbers and concepts (such as rates, etc.).

Discussion

The use of concept mapping to this extent in our College was unprecedented prior to the VM 642 course. In fact, within medical education, concept maps have not been widely used, although there have been a few applications reported in recent years (Mahler, Hoz, Fischl, Tov-Ly, & Lernau, 1990). Concept maps facilitate what Gowin (1981) calls "heuristic teaching," encouraging learners to reconstruct scholarly knowledge for themselves, and making the structure of knowledge explicit. Novak (1991) describes this power of concept maps as making the material "conceptually transparent," yielding great benefits to the learner's task of assimilating new information with existing knowledge.

The reactions of the students in VM 642 who saw the value of concept mapping only in retrospect are consistent with previous research ((Heinze-Fry & Novak, 1990); (Novak & Gowin, 1984)). It is not unusual for students to react to their first experience with concept maps with some ambivalence. When students are learning to construct concept maps, it may be difficult for them to see how their efforts will "pay off." Unless the meaningful approach to learning required by concept mapping is reflected in the assignments and in the assessment format, students will not see the benefit of their additional efforts, and will revert to rote approaches. As Biggs, (1989) stated:

> Deep learning is hard to facilitate, relying as it does on student interest, a willingness to get down to first principles, sufficient prior knowledge to be able to do so, and the means and ability to see oneself operate in context.. . . Two common reactions that lead to surface learning are cynicism and anxiety. Both lead to short-cuts during learning because each focuses attention on giving a product that will let the learner off the immediate hook. (p. 33)

Even with evaluation methods that reinforce a meaningful approach to learning, students may not recognize the benefit of concept maps until they reflect upon what they have learned. The veterinary students' responses to the course evaluation and to the questions on the post-test indicate that both concept mapping and meaningful learning "paid off" for them in this course.

In the 1996 offering of the course, enrollment was higher (84) and concept mapping played a more formal role. All students were expected to create a concept map mid-way through the course depicting the key concepts related to one of two superordinate concepts: intravenous fluids or solutes. The students took this assignment seriously, and produced some excellent maps. Perhaps even more gratifying to the course instructor were the several occasions that students were observed discussing their maps with each other, and with other students who had previously taken the course. Although some students needed reassurance that they were not expected to reproduce the one, "correct" map that presumably was in the instructor's head, for the most part the students rose to the challenge and spoke positively of the meaningfulness of the task for helping (in some cases, forcing) them to synthesize their knowledge.

Concept maps promote features of meaningful learning experiences: they are contextual, integrated, hierarchical, and constructed by the learner. Their visual nature and the fact that they are concise add to their power as tools for teaching and learning. Some of the characteristics that promote meaningful learning are also present in other methods for representing knowledge. For example, a recent study in which repertory grids were used reported the following positive outcomes:

> The process of discussing individual constructs as a group activity was more important than the repertory grid itself. When students were required to elaborate, explain, or defend their own positions, they tended to evaluate, integrate, and elaborate knowledge in new ways. Through the conversational use of the grids, the students were urged to review their personal resources and rebuild their ideas into more personally constructive patterns of meanings. With such opportunities, they developed qualitatively and quantitatively better forms of expressing their ideas, and with it, a better understanding of scientific concepts. (Bezzi, 1996) p. 210

Just as students benefited by discussing their concept maps with each other, those reflecting upon their repertory grids were better able to engage in a discussion of the material. These features that made the experiences meaningful are similar to the criteria Coles (1990b) articulated for elaborated learning in medicine. Arguing that elaborated learning "is the foundation for problem-solving and probably effective clinical reasoning," (p. 21) he has advocated contextual learning, involving context (grounded in concrete experience), information, and relating together of information. The goal in each situation is the same: to help students to develop an elaborated understanding of what they learn so that they are able to retain and apply their knowledge.

As previously described, much of the research on the structure of medical knowledge has focused on the development of problem-solving skills and the development of expertise. The fundamental problem these researchers seem to be addressing is complex: Not only is context prerequisite to integrated, meaningful learning, but meaningful learning seems to be prerequisite to the development of expertise. The problem is that these things do not necessarily flow automatically from one another. Students who learn in a meaningful context may still revert to rote methods; students who have learned meaningfully may not be able to apply relevant knowledge in novel situations. Students' misconceptions or alternative frameworks are persistent and very difficult to eliminate.

In a related study, Patel and her colleagues (1991) investigated medical students' abilities to explain pathophysiological concepts and to develop causal networks. The focus of the study was very similar in some ways to the goals of the VM 642 course: the researchers sought to document the ways in which medical students use their understanding of biomedical concepts in a clinical context. The results of the study indicated that students exhibited significant misconceptions that interfered with their abilities to relate clinical findings with pathophysiological mechanisms. The researchers observed several distinct types of errors in student thinking, and criticized instructional methods, citing the need to "systematically develop a clinically-relevant epistemology of basic science knowledge." They advocated a "principled scaffolding approach" to medical education to develop multiple levels of complexity in the ways in which biomedical knowledge is represented. (Patel, et al., 1991)(p.184)

In a longitudinal study of science concept learning, Novak and Musonda (1991) used clinical interviews and concept maps to follow the development of elementary students' understandings of science. Conceptual changes and elaborations were evident in the students' concept maps, as were misconceptions that persisted over many years. The audio-tutorial curriculum through which the science students in the study progressed had been designed to use common knowledge possessed by young children as a basis for early sessions, building progressively to more sophisticated scientific concepts. The results illustrate the significant impact early learning has upon subsequent understanding.:

> The remarkable finding of this study is that a relatively few hours of high quality science instruction in grades one and two apparently served as a kind of advance organizer for many students in later instruction in science.. . . We were surprised to see that when compared to a comparable sample of students who received no instruction in basic science concepts, the A-T ESP group showed many more valid conceptions and many fewer invalid conceptions over the study period. (Novak & Musonda, 1991) (p. 148)

Concept maps have served as advance organizers to subsequent learning, and they can serve as visual scaffolds for anchoring knowledge and for building elaborated representations of understanding.

One advantage concept maps have as metacognitive tools for promoting meaningful learning is that they may be used in any situation, and are not bound to a particular discipline or educational approach. Aimed not at the development of specific expertise but at helping students to learn meaningfully, concept maps are the manifestation of shared meaning and knowledge construction. Because they reveal valid as well as invalid propositions, they provide educators more direct access to the student's cognitive structure, increasing the chances that errors will be identifed and corrected. The epistemological element is not accidental; rooted firmly on constructivist principles, concept maps emphasize to students their role in knowledge construction, challenging any assumption that knowledge exists "out there," separate from human experience. As Wandersee (1990) states:

> The metaphor of the map seems quite appropriate for the holistic representation of what we know in and through science. The following generalizations from cartography can inform our understanding of such graphic representation of scientific knowledge: (a) mapping and knowing are closely intertwined; (b) maps are excellent heuristic devices; (c) both the map maker and the map reader have important responsibilities to fulfill if communication is to occur; (d) every map reflects both its data and the designer; (e) changes in maps reflect changes in understanding; (f) the prior knowledge of the map maker can have a great influence on the maps he or she produces; (g) all maps distort reality, both because of the very nature of mapping and because map makers have learned how to exploit distortion to achieve their communicative goals; and (h) maps have great cognitive, integrative, summative, and generative power. (Wandersee, 1990)(p. 930)

Concept maps can be helpful for summarizing expert understanding, and may hold promise for developing expertise. As in the VM 642 course, concept maps helped the course instructors and students to represent the interface between pathophysiology and medicine. By constructing concept maps of clinical presentations that incorporated relevant knowledge, students were better able to apply important principles to the clinical scenarios presented in the problem sets. Problem-solving skills do not exist devoid of content, but creating concept maps can provide visual scaffolds that make analysis of the problem and its solution easier. The positive reception concept maps received from the students attests to their value in facilitating understanding, and suggests their usefulness in applying biomedical knowledge to clinical practice.

Summary and Conclusions

The multiple use of concept maps played a pivotal role in the development and delivery of the "Management of Fluid and Electrolyte Disorders" course, which aimed at helping veterinary students to understand and apply knowledge of pathophysiological issues to clinical manifestations. Concept maps were used by the course instructors to introduce topics and to facilitate discussion, and by students to summarize and integrate their understanding. The use of concept maps to this extent was well-received by the course instructors and by students; 78% of the 62 students enrolled in the course in 1995 believed that the maps facilitated their understanding. The students' maps represented valid relationships as well as errors or misconceptions. This information was helpful to the instructors in providing detailed feedback to students, and it allowed the instructors to tailor their teaching to address specific issues. Performance on the final examination also reflected that the educational goals of the course had been met.

The data presented here are largely qualitative. Our experience with the VM 642 course is a case study of an effort to address the pedagogical problem of presenting complex material that historically had been very difficult for faculty to teach and for students to learn. Concept maps allowed the instructors to balance the interplay between the pathophysiological aspects of classic conditions in which fluids are administered with the knowledge of clinical manifestations prerequisite for developing a rational basis for therapy. Based upon the course evaluation, students found the two heuristics used in the course (concept mapping and the "three-column technique") to be very helpful in facilitating their learning. Most of the students (92%) thought that the course helped them to integrate basic and clinical science knowledge, and 86% thought the course built upon concepts they had learned previously in the curriculum. The performance of twenty students on a post-test administered a year later reflected good retention of the material, although it is difficult to draw conclusions from such a limited sample.

Much of the research in medical education on knowledge representation and students' cognitive structure has aimed at the development of problem-solving skills and diagnostic expertise. Concept maps have been used effectively in many fields, but most notably in science and mathematics education to promote meaningful learning and effective teaching. As metacognitive tools, concept maps may also be applied to the development of expertise, but only as representations of a given piece of knowledge. Experts can construct maps representing their area of expertise, but students will still be left with the task of assimilating information with their prior knowledge and experience. This would also be the case if the expert were to write a narrative description, give a demonstration, or create an interactive multimedia computer application. Identifying alternate ways to represent expert knowledge still leaves the question of how best to help students learn most effectively unanswered, because the task of constructing understanding is the learners' and theirs alone. Consistent with a constructivist epistemology, concept maps emphasize the central role of the learner in generating knowledge, but they also provide a tangible artifact of learning that can be shared.

In general, students' use of ineffective learning strategies and the number of persistent misconceptions that interfere with subsequent learning are so pervasive that an emphasis on meaningful learning (in medicine or any other field) continues to be warranted. If medical educators encourage meaningful learning strategies, perhaps the foundation for the development of expertise will also be more effectively laid.

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