SPECIAL REPORT

Mechanism-Based Diagnostic Reasoning: Thoughts on Teaching Introductory Clinical Pathology

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Abstract: **Teaching introductory clinical pathology to veterinary students is a challenging endeavor that requires a shift in learning strategies from rote memorization to diagnostic reasoning. Educational research has identified discrete cognitive stages required to achieve the automated, unconscious thinking process used by experts. Building on this knowledge, we developed a case-based approach to clinical pathology instruction that actively engages students in the learning process and links performance with positive reward. Simulated cases provide context and create a structure, or "schema", which enhances the learning process by enabling students to synthesize facts and link them with their causal mechanism to reach a defensible diagnostic conclusion. Web-based tools, including the "Problem List Generator" and tutorials, have been developed to facilitate this process. Through the collaborative Biomedical Informatics Research Group, we are working to further develop and evaluate Web-based instructional tools and new educational methods, to clarify the diagnostic reasoning processes used by experienced clinical pathologists, and, ultimately, to better educate our future students to be effective diagnosticians. (*Vet Clin Pathol.* 2000;29:77-83)**

Background

Our students

Those of us involved in teaching introductory courses in clinical pathology to veterinary students realize the task is an enormous one and not for the faint of heart. Clinical pathology curricula in veterinary schools throughout the country have many common features. Introductory clinical pathology is typically placed in the first half of the veterinary curriculum, often in the second year. The majority of students have completed at least 4 years of undergraduate training.

At the Virginia-Maryland Regional College of Veterinary Medicine (VMRCVM), our students average 5 years of preveterinary collegiate work. We see a rich variety of backgrounds ranging from traditional animal science and biology majors, to Russian history majors, PhDs, attorneys, engineers, and occasional MDs who are specialty board certified. By the time our students reach the introductory clinical pathology course, they have, in addition, completed 1½ years of the veterinary curriculum. At this point in their training, most students are intent on becoming private practitioners, and are predominantly interested in the small animal specialties. However, in recent years, a greater variety of veterinary fields are being considered as career options by students, even at this early point in their studies.

> *Editor's Note:*
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> Join your colleagues for a lively discussion and demonstration of teaching and web-based teaching tools at "Teaching Clinical Pathology: A Forum for Discussion" this fall at the 2000 ASVCP/ACVP meeting in Amelia Island, Florida. The session, entitled "Web-Based Teaching in Clinical Pathology" will be held Saturday, December 2, from 5 to 7 pm. Dr. Holly Bender will demonstrate the Problem List Generator and tutorials described in this report. Dr. Tracy Stokol will present "Web-Based Clinical Pathology in a Problem-Based Curriculum". The Teaching Clinical Pathology session is organized by the ASVCP Education Committee. You are cordially invited to attend, share your views, and enjoy a productive exchange of ideas about teaching!

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Veterinary students can be a delightful group of students to teach. Compared to their counterparts in other areas of the University, veterinary students, on the whole, are exceptionally motivated, focused, curious, and interested in the subjects they are pursuing. However, the process of educating this group of students holds plenty of challenges. By the time they reach the latter half of the second year, many have become notably frustrated, impatient and critical of their instructors, bored with some of their subjects, and disillusioned with foundation courses. Many complain that although they love and respect many of their anatomy and physiology teachers, they did not come to veterinary school to become basic scientists! Dealing with this now-volatile group of students is at times much like riding a fractious Thoroughbred: wonderful and exhilarating when it works, but a situation that can become disastrous in a hurry when things go wrong.

Our course philosophy

Clinical Pathology (VM8414) is the first VMRCVM course to introduce the concepts and skills involved in data interpretation and diagnostic reasoning. We emphasize synthesis of knowledge based on a sound foundation of pathophysiologic mechanisms. It is a pivotal course in the VMRCVM curriculum. Information learned in previous courses as well as in Clinical Pathology is drawn upon to solve diagnostic problems. These principles and skills form the foundation for subsequent medicine and surgery courses throughout the remainder of the curriculum. We attempt to help the students make the first giant step in a journey that advances the novice to an expert mode of diagnostic thinking. This is a big job to accomplish in 1 semester.

The instructional problems

When the previously-mentioned student characteristics are mixed with tremendous time pressures caused by a heavy credit load, many students resort to a "survival mode" of learning in order to maintain sanity and a successful grade point average. Survival strategies are learned throughout their prior educational experience and include cramming instead of disciplined learning, and rote memorization of facts rather than learning for mastery and understanding. These strategies have apparently served them well up to this point. Students often admit these may not be ideal methods of learning, but they are successful ways of passing tests in fact-based courses. When asked what mode of learning was used throughout the majority of their prerequisite courses, they overwhelmingly chime, "memorization!" Because the grading structure of prerequisite classes supports this notion, and because admission to veterinary school depends largely on grades, students are actually selected for their superior ability to memorize.

Diagnostic reasoning is a skill. Learning this skill is more akin to learning how to play the piano or training for an athletic event than preparing for prerequisite courses. None of us has ever observed a concert pianist or an Olympic athlete cramming for a competition. Cramming simply would not work, since the development of skills takes daily practice. While a background of facts is necessary to perform any skill, stopping at the rote memorization phase does not serve students well in applying the knowledge needed for diagnostic reasoning in Clinical Pathology. Entrenched and historically successful habits, however, are difficult to break, even by those with the best intentions. Once the cramming cycle begins in one course, work falls behind in the next until that exam requires the student to refocus and cram once again. This leads to students coming to class unprepared, not keeping up in courses, and constantly shifting focus by jumping from one frying pan into another. At least one of us admits that this same strategy was once used to cope with veterinary school when times got tough, some 20 odd years ago (apologies to Jan and Harold from HSB).

Like many of our clinical pathology colleagues, we emphasize mechanistic thinking as a strategy for success in learning the process of diagnostic reasoning. Successful diagnosticians have a solid foundation in basic pathophysiologic mechanisms; diseases are understood as disruptions of normal physiology. The manifestations of disease are essentially infinite in presentation and scope; certainly there are too many for anyone to commit to memory as isolated events. However, an organ such as the kidney responds to insults via a limited number of fundamental mechanisms. The multiple manifestations of disease are dependent on the severity of the insult and involvement of other organ systems. These manifestations, no matter the severity, can be tied to a finite number of fundamental mechanisms. Thus, if a student is armed with a strong basis in pathophysiology, he or she can reason through the various organ dysfunctions.

Research Into Learning

Experts vs. novices

There is an abundance of valuable research into learning that can be used to address our instructional problems. One goal of our Clinical Pathology course is to teach students how to work through the diagnostic process in the same way that an expert clinical pathologist would. However, clinical pathologists must spend thousands of hours of learning to attain competence in their area of expertise. Norman[1] contends that learning a complex skill takes at least 10,000 hours of practice of the targeted performance. Complex learning has been characterized by 3 stages: (1) accretion (fact learning), (2) structuring (using facts in procedures—strengthening some connections and "pruning" or isolating facts that are not used), and (3) tuning ("compiling" routines to make performance of the processes automated and devoid of conscious effort).[1]

The cognitive processes of experts and novices are quite different, so it is little wonder that teaching a novice to think like an expert is challenging. Experts have a huge library of facts specific to their area, and thousands of "organizers" to help them "chunk" facts efficiently. Facts alone are insufficient for adept problem solving and diagnostic reasoning. Experts have developed "fluid" memories such that the necessary facts are connected to the specific context of the problem-solving process. Novices cannot behave like experts because they do not have the organizers or fluid connections that are developed through practice. They do not see the same problems, so they must follow a linear procedure or algorithm. Their attempts to perform a complex process are deliberate and require tremendous mental effort; whereas, the expert has automated the task to the point of not having to think about its individual components or steps.

What is happening in the mind of the learner as he or she makes the transition from novice to expert? Miller[2] conducted a number of studies that led him to conclude that humans are capable of remembering only 7 discrete bits of information (± 2 bits) for a short period of time without "processing" them (see for examples[3,4]). Miller concluded that people overcome this shortcoming by "chunking" information, ie, recoding small bits of information into larger chunks that contain the smaller, related bits of information.[2] The notion that the mind arranges information as a result of associations between types of data has led to the concept of "schema".[5,6] A schema is a knowledge structure that accommodates or facilitates the mental process. According to Winn and Snyder[5] a schema is characterized as follows: "(1) It is an organized structure that exists in memory and, in aggregate with all other schemata, contains the sum of our knowledge of the world. (2) It exists at a higher level of generality, or abstraction, than our immediate experience with the world. (3) It consists of concepts that are linked together in propositions. (4) It is dynamic, amenable to change by general experience or through instruction. [and] (5) It provides a context for interpreting new knowledge as well as a structure to hold it." The process of turning new knowledge into "long-term" knowledge accompanies its accommodation in the learner's schema. While a variety of models are used to represent schema, it is generally felt that methods of teaching that build on schema (ie, that facilitate the establishment of connections between related and existing concepts) are more likely to be effective than methods that do not. In other words, learning by association with things that we already know to be true is the most effective way of committing information to long-term memory, the process that accompanies the development of expertise.

Schema-building teaching methods: context and cases

One concept that emerges routinely from the literature on learning theory is the importance of learning in a meaningful context.[7-9] Context provides an organizational structure for information being learned, and, it may be argued, facilitates the construction of meaningful schema. In veterinary education, the ideal context would involve real work with real patients. Because it is not always possible to provide authentic learning contexts, some educators rely on simulated cases as the next best thing. Drs. Oscar Schalm, Robert Duncan, and Keith Prasse introduced this mode of education into the field of veterinary clinical pathology at the University of California and the University of Georgia during the 1960s and 1970s. Although simulated cases are inefficient in transferring information compared to traditional lecture methods, many of us have followed in their footsteps because of the richness and effectiveness of the learning process. In the context of medical education, simulated cases provide paper or computer-based information about a patient, including the history, signalment, physical examination, and laboratory data. In addition to providing a "real-life" context, simulated cases have the additional benefit of providing a narrative framework or a story for the attachment of significant concepts. The idea that a medical condition is affecting a certain patient in a particular way grabs students' attention in a way that a lecture using isolated laboratory data cannot.

Tightly tied to the concept of context is the suggestion that for learning to be most effective, students must be actively engaged in the learning process.[8,10,11] In addition, educational research suggests that a variety of presentation stimuli is better than just one. Students learn more by an activity that requires them to produce evidence of understanding (discussion or teaching) than by sitting in a lecture and listening.[12] The success of the recent explosion in multimedia teaching modalities, and the popularity of discussion groups support these findings. Research also suggests that expertise is best developed when the learner is allowed to work with a complex, authentic task, particularly when accompanied by expert support of some kind.

Mandin, Jones, Woloschuk, and Harasym[13] suggest several ways of providing this kind of supported practice in medical education, which they refer to as providing an "expert scheme." One way is to provide students with a possible diagnosis and the data that lead to that diagnosis and require the students to "fill in the lines." Another approach is to provide students with a logical scaffold or "scheme" for organizing data and have them attach relevant data to that scheme. They argue compellingly that if students learn knowledge in the context of an expert scheme, or network, they will be more likely to remember the knowledge as it relates to other pieces of knowledge. In the language of cognitive apprenticeship, their proposed expert scheme would provide a scaffold for learning and facilitate effective schema construction.

Behaviorism and the rewards system

The use of course credit as a positive reward is based on a behavioristic approach to learning, as learners are more inclined to complete a given task in order to receive positive reinforcement.[11] Students generally respond well to clear guidance from instructors concerning course expectations when performing the tasks at hand. However, students pay more attention to this guidance when it is tied to a reward system, such as course credit. All too often, we send students confusing messages by telling them not to cram during veterinary school, but then structure our courses with a midterm and a final examination.

Theory in teaching and learning suggests that a successful teaching intervention (in a complex domain such as clinical pathology) involves: (1) real, contextual problems (such as cases), (2) opportunities to deal with those problems with expert support, and (3) clear course goals with a carefully constructed reward system to reinforce those goals. The target population (eg, a class of sophomore veterinary students) already has accomplished the first stage of the learning process, accretion. They have learned many facts and have advanced through their careers by memorizing those facts. At this point in their education, students must develop the diagnostic processes necessary to synthesize facts from courses in anatomy, physiology, and pathology, and thereby enable medical problem-solving in context.

The VMRCVM Approach

The course

Clinical Pathology (VM8414) is a 3-credit course that has been developed over the past 10 years. Ninety students are typically enrolled and the course is offered during the second semester of the second year of the veterinary curriculum at the VMRCVM. Clinical Pathology is composed of a mix of didactic lectures, case discussion laboratories, and wet laboratories. Because it is an introductory course, classical pathophysiologic mechanisms of disease are emphasized. Controversial areas are reserved for subsequent courses, after the basics of the discipline are mastered.

Lessons learned from the educational research detailed above are used to promote learning in the course. Electronic illustrations on computer projected slide presentations are used to stimulate the senses of a variety of learners. Techniques to promote student involvement in the learning process are interspersed every 10 to 15 minutes of lecture, such as small group discussions, question and answer periods, and metaphor demonstrations. Metaphors generally consist of common household items used to illustrate concepts that historically are difficult for many students to comprehend or remember. For instance, a household strainer is used to illustrate glomerular filtration. Substances that are freely filtered, such as glucose (illustrated by pouring sugar through the strainer), sodium (table salt), and ketones (fingernail polish remover), pass through the strainer readily. Substances that are restricted by the glomerular membrane in health, such as albumin (sesame seeds), immunoglobulins (pasta wheels for IgM), and red cells (a red apple), give the students a sense of scale. This metaphor demonstration promotes the learning process by associating glomerular filtration with concepts the students already know to be true from daily life. Involving individual class members in each metaphor demonstration holds students' attention and invariably adds a touch of levity. Additionally, wet labs are timed carefully to reinforce concepts discussed in lecture and to show the practical aspects of laboratory medicine.

The casebook and textbook

The Clinical Pathology course is designed around a series of ~100 cases of increasing complexity. These cases are distributed to students in the form of a casebook along with a textbook written by the instructors. Reading assignments from the textbook are carefully timed to coincide with the cases, which illustrate salient concepts. The cases portray common diseases of domestic animals and consist of a short history and typical laboratory data changes. Case material is restricted to classical data abnormalities in order to build a foundation for less characteristic (and admittedly more realistic) data in later courses.

Initial cases are very simple, with few data abnormalities representing a small number of mechanisms of disease. Case 1, for example, introduces anemia using little more than the erythroid parameters. As the course progresses, the number of data abnormalities increases incrementally to introduce each new subject at hand. By the end of the course, cases are quite complex, with a long list of data abnormalities and numerous causal mechanisms. Many of the mechanisms found in later cases are repeated from previous cases (eg, a stress leukogram and anemia of chronic disorders are seen frequently), with 2 or 3 new concepts added per case. This repetition builds student confidence, especially when individuals realize their newfound ability to recognize and properly explain data patterns in subsequent (and different) disease presentations.

Mechanism-based case analysis

Students are asked to construct a case analysis or problem list for each case prior to the day it is discussed in class. They are directed to create problem lists in a very specific manner to take advantage of the scaffolding principles discussed earlier. Students first are asked to extract relevant observations from the case history. Next, the data are evaluated incrementally starting with tasks that involve low-order thinking (identifying data abnormalities), proceeding stepwise to slightly higher-order thinking (naming the abnormalities with the proper medical terminology), and lastly, performing tasks that require high-order thinking (constructing a causal hierarchy). This hierarchy is built by grouping related data abnormalities as supporting evidence for the causal mechanism. The resulting problem list looks like an outline with pathophysiologic mechanisms as major headings and data abnormalities along with historical items as supporting evidence. Each mechanism becomes an incremental diagnostic conclusion and the list develops into a compelling argument for the diagnosis. Students are advised to wait until they have built the entire list before completing the final step in the process: forming a final diagnosis. The suggested amount of time spent on homework for each case (including the associated reading assignment) is 40 minutes. We believe strongly that this practice promotes curiosity and creates a prepared mind that is more inclined to understand the processes discussed in class, even if the student is totally off-base in their initial attempt at a problem list.

Each student in the class is required to present at least 1 case argument in front of his or her peers. The student meets with the instructor to discuss the case prior to its presentation in class to make sure that they are clear on the instructional goals for the case and that they have a defensible problem list. The student presents the case and associated rationale while the instructor writes the problem list on an overhead projector. The instructor plays "devil's advocate" during the presentation, asking the student to explain and defend the pathophysiology of each mechanism of disease and how it relates to the case at hand.

Student assessment

Course evaluation methods are based on case material, consistent with the instructional methods used in the course. One-third of the course grade is based on submitting all problem lists before the associated case is discussed in class. Practicality dictates that these lists be submitted on forms on which the student number can be optically scanned by our testing service to award credit. The second third of the course grade is based on a series of 21, unannounced, 10-minute quizzes based on cases recently discussed in class. Each student is allowed to drop their 2 lowest quiz grades so that illness and important life events can be attended without undue penalty. The remaining third of the grade is based on a comprehensive final examination. The final exam is a collection of 8 cases and associated multiple-choice questions. These particular cases are new to the students, but each contains mechanisms seen repeatedly in cases throughout the course.

Those who "get it" vs. those who struggle

Students with success in previous, fact-based courses that rely heavily on rote memorization are not necessarily the same individuals who perform well in the Clinical Pathology course. Success in this course is instead dependent on analytical skills and synthesis of knowledge. Each year, a group of students emerges that seems to grasp the diagnostic process inherently. These students are exhilarated and relieved that (finally!) they have found a course that is clearly relevant to their career goals. Another group emerges as well: students that seem to struggle endlessly. For this group, learning the diagnostic process is a difficult and often overwhelming task, especially in the early portion of the semester.

Tying course concepts to cases is exceptionally motivating to students, but many become frustrated when the process does not come easily. Some students develop a staggering emotional investment in the diagnostic process and view the course as an acid test that sorts out who will—and who will not—become "good vets." These individuals tend to judge themselves harshly and prematurely if they have to work hard to develop the skill. All students have previously observed their mentors (primarily private practitioners) performing the diagnostic process for years, and the invisible mental activity required to complete these tasks might have appeared effortless. These were however, experienced professionals, with highly developed cognitive skills developed through a great deal of practice.

Our experience shows that students having difficulties with the transition from rote memorization to analytical thinking often jump to diagnostic conclusions based on poorly supported assumptions rather than identifying and analyzing the laboratory data abnormalities to make sound, defensible conclusions. These individuals tend to skip over much of the available evidence and ignore discriminatory laboratory data if it does not support a preconceived diagnosis. After all, there are many entrenched habits to overcome. Students are accustomed to quick, immediate responses in their fact-based courses and many attempt to apply the same strategies to the diagnostic process. It may appear that their more experienced mentors also jump to conclusions, and the student may be emulating this activity. Unfortunately, second year students do not yet have the experience or cognitive skills to successfully perform such tasks. Jumping to hasty and erroneous conclusions can result in the formation of bad habits and lead to trouble in their future careers.

This case-based approach to teaching Clinical Pathology is exceptionally motivating. Many students spend considerably more time than the recommended 40 minutes per case, much of which is devoted to looking up additional information specific to a particular disease. Although additional activity cannot be prevented (even if it was desirable to do so), a complete knowledge of medicine is not necessary for success in this course.

Results of interventions and rewards

Students with excellent analytical skills will succeed at the diagnostic process no matter how we deliver the Clinical Pathology course. Interventions such as the reward system are designed for those who struggle. The frequent unannounced quizzes are consistently detested in the early portion of the course, but course evaluations show repeatedly that students credit the quizzes with their change in behavior from cramming to doing continual small amounts of studying. These new study habits are credited for their ability to keep up with the course and develop better diagnostic skills. An unexpected benefit of the quizzes is that class attendance is nearly perfect, since the unannounced quizzes are administered during the first 10 minutes of class.

Prior to course credit being awarded for problem lists, students were on their honor to complete homework assignments. These assignments were generally completed during the initial portion of the course, but compliance fell off when competing interests such as midterms in other courses complicated their lives. The Clinical Pathology course deteriorated during these times as students arrived in class unprepared, and simply copied and memorized the problem list presented in class.

The use of optical scanning forms for problem list submission prior to class has dramatically improved compliance. The class of 2001 failed to turn in only 10 out of nearly 9000 problem lists (90 students $\times$ 100 problem lists). However, the optical forms have major shortcomings. The forms use free text entry and students can (and do) readily skip available data. In addition, the forms lack a framework for forming diagnostic conclusions. Finally, there is no practical way of evaluating each problem list. These shortcomings motivated the development of an instructional tool to help the students work through problem list formation and the diagnostic process in a stepwise manner.

Current and Future Work

The Problem List Generator

An instructional computer tool called the "Problem List Generator" (PLG) is currently being developed at Virginia Tech to help second year veterinary students acquire skills in diagnostic reasoning and laboratory data interpretation. The PLG is an interactive, client-server application written using the Java 2 Platform (Sun Microsystems, Inc., Palo Alto, Calif, USA) and is accessible from any computer connected to the Internet. The PLG is designed to reinforce good habits in data interpretation, and discourage the development of bad habits typically employed by novices, such as jumping to conclusions. It also overcomes the aforementioned shortcomings of the optical scanning forms. The PLG requires students to approach each case in a thorough, stepwise manner by guiding them systematically through a series of ~100 problem-solving experiences. Each case starts with low-order thinking tasks (identifying and naming all the abnormalities), and then proceeds stepwise through the higher-order thinking necessary to generate sound diagnostic conclusions based on pathophysiologic mechanisms of disease. This higher-order thinking is facilitated by new "drag and drop" Java tools on a computer grid as the student associates data abnormalities with their causal mechanism in a hierarchy. The student is allowed to rearrange this hierarchy as needed to construct a sound argument. The resulting outline is a causal hierarchy that supports a series of mechanistic conclusions and leads to a logical, defensible argument for the diagnosis. The PLG is purposefully designed so that the students cannot skip to diagnostic conclusions without first identifying, naming, and explaining all data abnormalities. Once the case argument is submitted to the server database, the student is granted instant feedback in the form of a problem list created by the instructor. The PLG also solves an administrative problem. Tabulating the nearly 9000 problem lists generated by a class during the course is clearly difficult. With the PLG, electronic handling of the problem lists allows instant feedback in the form of course credit, which further encourages students to keep up with the incremental nature of the assignments.

The second year VMRCVM veterinary students beta-tested the PLG in their Clinical Pathology course during Spring Semester 2000. The tool simultaneously underwent a rigorous formative assessment as the subject of a graduate level course in Virginia Tech's College of Human Resources and Education. The resulting feedback will drive functional enhancements to the PLG and facilitate its continuing evolution. Preliminary evidence shows the PLG helps students account for all data abnormalities, and provides a successful framework for a systematic, mechanistic method of thinking through case problems. In the future, the PLG will be linked to a series of comprehensive, interactive, Web-based tutorials containing rich multimedia content to promote active learning and further reinforce concepts illustrated by the cases. An electronic means of comparing an expert's diagnostic rationale to that of the student's (the novice's) is currently under development. In the future, we see potential for using this tool to compare the thinking processes of experienced clinical pathologists and thereby more fully understanding the elusive "black box" of diagnostic reasoning used by experts in our field.

The Biomedical Informatics Research Group

The VMRCVM clinical pathologists have (quite frankly) solved the instructional issues consistent with their training and expertise during the 20 years since the College's inception. However, several stubborn problems persist that are inherent to our educational system and complicated by entrenched habits. We believe that the solution to these problems requires a fresh approach using an interdisciplinary team of professionals who are trained in complementary fields and are intrigued by tackling perplexing and challenging instructional dilemmas.

The Biomedical Informatics Research Group (BIRG) is a team formed to work on instructional problems in veterinary clinical pathology. The BIRG is a multidisciplinary group of faculty, graduate students, and veterinary students from the VMRCVM, Virginia Tech's Department of Teaching and Learning, Department of Computer Science, and Department of Accounting and Information Systems, as well as the University of Virginia's College at Wise, Va. The BIRG is composed of individuals trained in veterinary clinical pathology, instructional design, educational technology, educational psychology, computer science, interface design, informatics, and assessment techniques. Each member plays a vital role in the group's synergy, and the cross-pollination of disciplines is key to creating unique computer learning tools. We are working together to further enhance and extend our new instructional tools and educational methods, and to clarify our own diagnostic reasoning processes, improve our skills, and better educate our students in the future. ◊

Acknowledgments

The development of the PLG is supported by the United States Department of Agriculture and Virginia Tech's Center for Excellence in Undergraduate Teaching, ASPIRES program, and the Office of the Provost.

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