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The Diagnostic Pathfinder: Ten years of using technology to teach diagnostic problem solving

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Educational Methods | Educational Technology | Other Veterinary Medicine

Comments

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Abstract

The Diagnostic Pathfinder has been used for nearly ten years at multiple colleges of veterinary medicine to teach diagnostic problem solving. A number of prior studies show this tool to be effective. Research in medical diagnostic problem solving provides hints, but no unambiguous answers regarding how such a tool should be designed. This in-depth review of the interface discusses each interaction in terms of how that interaction relates to the tool's success. Nine faculty members who have taught using the Pathfinder during the last decade responded to interview questions regarding the tool. Their responses supported what had already been learned – that there is benefit when learner and instructor use the same process for solving a diagnostic problem, and then compare results, and when students learn in the context of realistic problems. Additionally, instructor responses suggest that the Pathfinder has been effective because it has 1.) enabled precise communication among experts and learners in a field where there is no generally agreed upon format for precisely communicating understandings of interrelationships between mechanisms of disease and clinical laboratory data, and 2.) provided a framework for manipulating data that respects the limitations of human memory and invites a thorough, explicit, and "artistic" rendering of the rationale.

It has been a decade since a small group of researchers, brought together by one of the authors (HB) first met at Virginia Tech to discuss the need for a better way to help veterinary students learn how to interpret laboratory data. Those initial meetings led to ten years (and counting) of software design, development, evaluation and revision which produced the Diagnostic Pathfinder, a computer-based tool that helps veterinary students learn and practice diagnostic problem solving. The Pathfinder has now been implemented for clinical pathology instruction at six colleges of veterinary medicine and is currently being adapted for instruction in clinical pharmacology, toxicology and internal medicine.

This story is worth telling because the Pathfinder has been part of the solution to an old and tenacious difficulty--helping students learn diagnostic problem solving. The story of the Pathfinder seems worth telling, too, because the richness of our data was not derived from highly controlled experimental studies, though results from a number of quasi-experiment studies have proven remarkably consistent. Rather, our research has high ecological validity. – All of it has occurred in a diverse range of authentic instructional settings with many students solving real learning problems.

Theoretical Framework

In explaining how research with the Pathfinder (and its earlier version, the Problem List Generator) has contributed to what we know about teaching problem solving, we will couch it in the medical education literature, and refer to some relevant broader educational literature and theory. In providing this framework, we do not wish to imply a theoretical pedigree for the Pathfinder, but rather we are painting a picture of what has occurred in several fields relevant to the Pathfinder's creation which help to situate it theoretically. We begin with problem solving, specifically highlighting research in medical diagnostic problem solving. Then we move to a discussion of how the Pathfinder fits in a classification of learning tools, and finally to a description of the Pathfinder itself.

Problem Solving

Problem solving means addressing the discrepancy between what the problem solver knows and what he/she must figure out or do to solve a problem (Wenke & Frensch, 2003). As such, problem solving is a learning exercise -- it involves the unknown. What is known about human cognition in general provides insight into why it would be difficult to teach problem solving. Problem solving is an information/knowledge management problem. Particularly in complex and/or ill-structured domains, it requires the problem solver to manage a variety of information (some of which likely is new) in new ways. This process places a significant demand on domain knowledge and working memory (Pretz, Naples, & Sternberg, 2003; Wenke & Frensch, 2003).

If problem solving is addressing the gap between what is known and what must be figured out to solve the problem, then three important aspects of this definition clarify why problem solving can be difficult to study and teach. (1) Nearly any given task could constitute problem solving given the right conditions. For example, performing a routine surgery would constitute a legitimate problem solving activity for most people, but likely would not for a surgeon with experience and expertise with that particular kind of surgery. (2) Closely related to the first concept, as soon as anyone fully understands how to perform a problem solving task, that precise task no longer constitutes problem solving for that person. For example, for someone just beginning to learn a foreign language, the formation of nearly every sentence in that language is a legitimate problem solving activity. Naturally, as vocabulary and syntax become familiar and automated through use, the speaker encounters fewer problem solving tasks in the course of everyday speech. (3) For an activity to qualify as problem solving, the solution must be arrived at through the learner's manipulation of the information (knowledge and skills) relevant to solving the problem. In other words, just because the problem got solved, doesn't mean problem solving occurred. Problems frequently are solved by accident or serendipity. For example, a schoolboy who realizes right before bed that he has neglected to do a major homework assignment that is due the next day has a problem. If he stays up late and gets his homework done, or manages to talk the teacher into giving him an extension, you might consider that he has been a good problem solver. If, on the other hand, he goes to bed, hoping for the best, and an unexpected snow storm results in school being closed for several days, his immediate problem has been solved, but not because his action constituted problem solving. Hence, while compelling, it is not quite complete to refer to problem solving as simply "what you do when you don't know what to do" (Wheatley, p. 1 from (Bodner, 1991 p. 22)). By our definition, "what you do when you don't know what to do" is only problem solving if it emerges from a purposeful manipulation of information that leads to knowledge which, if employed again, would solve the identical problem again. Otherwise, the solution was just plain luck.

Following decades of research in multiple domains, it is considered a truism that there is no such thing as a "general" ability to solve problems; this ability doesn't transfer across domains. Therefore, many researchers have turned their attention to helping learners become more expert-like in their approach to problems in specific domains, with particular emphasis on domain knowledge, while de-emphasizing what expert problem-solvers do when faced with previously unencountered problems.

In this chapter we focus most of our attention on a specific kind of problem solving -- diagnostic problem solving. Diagnostic problem solving is a sub-type of problem solving that involves determining if a system is deviating from its normal state and if so, the reason for the deviation. The terms c*linical problem solving* and *clinical reasoning*, which in the medical context would also involve recommending specific steps or treatments to return the system (patient) to a normal state, are often used interchangeably with the term diagnostic problem solving. However for the purpose of this discussion, we will only deal with the skill of arriving at the diagnosis, and not of providing treatment. Diagnostic problem solving can be very demanding, whether the system being diagnosed is a complex human-designed system (such as an aircraft) for which precise and detailed blueprints exist, or a complex biological system (e.g. a dog or horse) for which clinicians cannot consult a complete and exhaustive blueprint, and where no two cases are identical.

Explanations of, and models for, understanding diagnostic/clinical problem solving and how to teach it have proliferated over the past several decades in the medical education literature (Barrows & Feltovich, 1987; Forde, 1998; Groen & Patel, 1985; Hershey & Baron, 1987; Kassirer, 1989; Kassirer, Kuipers, & Gorry, 1982; Mandin, Jones, Woloschuk, & Harasym, 1997; Mattingly, 1991; Rennels, Shortliffe, Stockdale, & Miller, 1987; Rizzi, 1994; Schmidt, Norman, & Boshuizen, 1990; Upshur, 1997). These studies have tended to focus on faults in expert clinical problem solving, explorations of how experts and novices approach and/or think about problems, and how specific instructional interventions affect how well students learn to solve problems.

Many studies have explored the diagnostic errors made by practicing clinicians (e.g., (Bergus, Chapman, Gjerde, & Elstein, 1995; Bordage, 1999; Christensen, Heckerling, Mackesy, Bernstein, & Elstein, 1991; Lyman & Balducci, 1994). Bordage (1999) identified twenty nine error types falling within one of three broad error categories: 1. data gathering, 2. data integration, and 3. situational factors. In a medical problem solving setting, data gathering would refer to all the activities the clinician engages in to acquire information relevant to solving the problem, including performing the physical exam, collecting the history, etc. Data integration involves making sense of the data once it is gathered. Situational factors aren't planned elements of the problem solving process, but affect it nonetheless, and include influences such as stress, fatigue, and work load. Our work has focused exclusively on addressing the second type of error: data integration.

Relatively trivial errors in the data integration process can produce significant diagnostic errors. For example, Christensen, Heckerling, Mackesy, Bernstein and Elstein (1991) found that medical practitioners made diagnostic mistakes for no other reason than the framing of the problem (i.e. a 95 % chance of survival is reported, as opposed to a 5 % chance of mortality.) Similarly, Bergus, Chapman, Gjerde, and Elstein (1995) found that family physicians erred in diagnosis as a result of whether or not the medical history was presented before or after the clinical data were presented. These two studies are representative of many more (Bordage, 1999), and illustrate that improving future clinicians' success at data integration in problem solving has real and pragmatic potential value.

There have been many attempts to improve how learners learn to solve diagnostic problems. One popular strategy in the area of medical diagnostics has been to attempt to base instruction on understandings of the ways that expert diagnosticians think. Such studies span nearly four decades (e.g., (Bordage & Lemieux, 1991; Chang, Bordage, & Connell, 1998; Cholowski & Chan, 1992; Coderre, Mandin, Harasym, & Fick, 2003; Ferrario, 2003; Groves, O'Rourke, & Alexander, 2003; Hardin, 2003; Rikers, Loyens, & Schmidt, 2004; Schwartz, 1989; Stevens, 1991). Thus far, these studies have failed to provide results that easily translate into improved teaching. Norman (2005) provided a concise chronology of this research and its trends, showing how research in this area has shifted from a focus on general problem solving strategies (in the 1970's) to a focus on what kinds of things expert diagnosticians remember and how those things are remembered (the 1980's) to a focus on mental representations of knowledge (the 1990's and beyond). Norman concludes that these studies have proved inconclusive and that "there is no such thing as clinical reasoning; there is no one best way through a problem" (p. 426).

Our research has not ignored the issue of how experts think through problems, but has focused more directly on how to help learners improve their performance as problem solvers. For those to whom this approach might appear to be getting the cart ahead of the horse, we would simply point out that one implication of Norman's meta analysis is that waiting to be sure we fully "understand" expertise before attempting to teach it could involve a considerable wait.

The Diagnostic Pathfinder and other Learning Tools

The over-all approach used to design the Pathfinder could best be described as pragmatic. We employed a traditional instructional systems development (ISD) approach to guide the overall process (Dick & Carey, 1996), and used well-defined and prescribed models for front-end analysis (Tessmer & Richey, 1997), interface design (Hix & Hartson, 1993), and formative evaluation (Tessmer, 1993).

Apart from an ISD-based design context, theoretically, we made three important assumptions: 1) **A mechanism-based approach.** In medical diagnostic problem solving, students should have practice explaining medical findings in terms of the underlying pathophysiologic *mechanisms* of the case, 2) **An authentic problem**. Students will learn best by manipulating realistic case data in a context that is as authentic as possible. 3) **An expert scheme.** In manipulating data, students should be guided in following a process that is known by experts to produce accurate results.

A mechanism-based approach

A mechanism-based approach focuses on a thorough understanding and explication of the underlying processes (mechanisms) that produce disease or compromise health, and how those processes occur within and among body systems. This assumption is intuitively appealing, and is consistent with research showing that effective diagnosticians have more elaborated knowledge structures (Bordage, 1994) and more thorough knowledge representations (Chang et al., 1998) than their less effective counterparts. However, there is evidence that many practicing clinicians rely little on underlying pathophysiology in their routine work, though they rely on it when they encounter non-routine problems (Schmidt et al., 1990), and Ark, Brooks and Eva (2007) found that inexperienced students performed best on diagnostic analysis involving EKG information when encouraged to utilized both analytic and non-analytic (gut instinct) reasoning. Clearly, then, there are various reasoning approaches that contribute to successful performance in the expert diagnostician. However, for the design of this particular tool we operated under the assumption that diagnostic errors due to data integration problems would be reduced when students learned to understand as thoroughly as possible, and effectively manipulate underlying pathophysiologic data. We opted for a design that would support elaboration of the underlying rules/concepts of pathophysiology.

An authentic problem

Central to the design of the Diagnostic Pathfinder is the assumption that students will learn how to solve problems only when they have practice doing so. Pathfinder problems contain signalment (the animal's age, species, breed, gender and neuter status), history (a brief description of the presenting complaint and context), and laboratory data. The desired solution is a coherent and reasonable explanation of all available data. Such problems are not as broad as many problems encountered by the practicing clinician. A complete clinical problem would involve several activities which Pathfinder problems do not, including performing a physical exam, eliciting a history, selecting diagnostic tests, and creating a treatment plan. However, a Pathfinder problem does constitute a full "referral" problem, such as those routinely seen by clinical pathologists, or by a clinician who has been asked to interpret the laboratory data of a case for a colleague. In such instances, it is a common practice for a diagnostic problem solver to respond to a brief historical description and laboratory data. Many teaching strategies involve the use of authentic problems, or cases, including Problem Based Learning, Case Based Learning, Situated Cognition, and many others.

An expert scheme.

Mandin et al (1997) proposed the idea of identifying and teaching an expert process for medical education in recent history, but the idea of seeking to clearly understand an expert process and then teach learners to emulate it is an old one, and is implicit in the emphasis that instructional design puts on task analysis. There are two potential dangers in attempting to analyze an expert process and then teach it. First, not all experts approach the same problem the same way, so the designer must trust the expert with which he/she is working to have a “good” expert scheme. Second, expertise is often tacit, which can lead to naïve attempts to simply get the novice to behave like the expert does, without the underlying knowledge structures which support that behavior. The expert scheme that we adopted had anecdotal support in one of the author’s (HB) experience in solving diagnostic problems and teaching hundreds of veterinary students how to do so. Specifically, the expert scheme involved guiding students to do the following for each encountered case: 1. Extracting data from the history, 2. Identifying all abnormal laboratory data, and 3. Explaining the laboratory data without ignoring any abnormal data. In addition to this scheme, borrowing from identified best practices in instructional design, we added a fourth process -- expert feedback directly following completion of the case.

When first exposed to the Pathfinder, many assume that it is an expert system-based tool. It is not. Products based on expert systems are common in problem-solving instruction. Such tools attempt in some way to shadow the learner through the problem solving process, and provide guidance or feedback in an adaptive way, depending on the decisions that the learner makes. Work with such systems dates back more than two decades in medical education (e.g. GUIDON, (Clancey, 1993)). To function successfully, expert-system based learning tools must leverage a database that is both sufficiently complete and sufficiently flexible to support a variety of scenarios. They must also interact appropriately with the learner. The rationale for intelligent (expert system-based) tools is that they can individualize instruction, just as human tutors do. While achieving effective results from intelligent tutoring systems has not been easy, there are a growing number of successes particularly in relatively well-defined domains such as mathematics. We chose not to pursue an expert-system based approach both because of the daunting complexity of adequately capturing the domain of veterinary clinical pathology (including multiple species and body systems), and because we felt that we could design an "unintelligent" tool that could engage students in relevant problems as effectively as an intelligent tool might.

Another teaching tool commonly used to assist this kind of learning is the simulation. Simulations, often computer -based or computer -assisted, attempt to provide an artificial environment that approximates a real one, and can be manipulated by the learner; as suggested by their name, simulations *simulate* reality. Simulations, both high and low fidelity, computer based and not, are common in medical education for teaching everything from clinical reasoning to palpation or other clinical procedures. They are also common in other domains. The Pathfinder bears some resemblance to simulations in that it presents authentic problems in a relatively authentic format. Problems that are referred for consultation typically consist of a laboratory data sheet and a written history. In that sense, the Pathfinder simulates an authentic problem solving situation. However, the Pathfinder provides more than that; it also guides the learner in specific ways, provides additional information such as images of organs, photomicrographs, specimens, etc., and supports problem manipulation in a fashion that goes beyond what would ordinarily be encountered in the *real world*.

We have classified the Pathfinder as a cognitive tool. Cognitive tools support cognitive process by extending cognitive or symbolic function, and providing processes that can be internalized by the mind and used independent of the tool (Kozma, 1987; Salomon, 1988). This definition allows for broad interpretation of the term *cognitive tool*; published examples of cognitive tools include the abacus and spreadsheet (Salomon, 1988); semantic network tools, expert systems shells, systems modeling software (Jonassen, 2003); and the calculator (Ruthven & Chaplin, 1997). Our use of the term cognitive tool is most similar to Jonassen's (2003) who drew on research illustrating the connection between how individuals represent problems and their ability to solve them (e.g. Mayer, 1976; McGuinness, 1986; Pape & Tchoshanov, 2001; Zhang, 1997). Jonassen's idea was that tools that help learners learn to represent problems, will also help them learn how to solve them. We did not set out to build a "cognitive tool," but, analyzing the tool as it exists and as it functions, we believe this is the best classification for it. Just as a spreadsheet extends and supports the individual's ability to learn about use numbers, the Pathfinder extends and supports their ability to learn about and manipulate pathophysiologic data.

The Diagnostic Pathfinder

The Pathfinder has been described elsewhere (Danielson, 1999; Danielson, Bender, Mills, Vermeer, & Lockee, 2003; Danielson et al., in press). We intend this description to be more complete and detailed than previous descriptions. Together with each element of the description we will include a discussion of how its function can be explained theoretically. We borrow from theoretical ideas somewhat eclectically, rejecting the notion that theory must be pure or from one perspective to be useful in guiding or explaining instructional design.

The Pathfinder is a Java-based program that runs on both Windows and Macintosh platforms. In most situations, a copy of the program and the cases are downloaded from the Internet onto a personal computer, where the majority of work can be performed without an Internet connection. Reconnection to the Internet is required for submission of completed cases.

The Pathfinder consists of 6 major windows: 1) Signalment/History/Physical Exam, 2) Lab Data, 3) Construct Diagnostic Path, 4) Make Diagnosis, 5) Expert Diagnostic Path, and 6) Submit for Credit.

After logging on, the students select the assigned case from a list (Figure 1) and are presented with the patient's signalment, history, and physical examination findings (Figure 2). From the information provided, students must extract relevant words or phrases by highlighting them and clicking “Record Observation”, or they may click on “Record Observation” to open an “Add Observation” dialog box into which they may type the relevant data. All observations identified by the learners during this interaction appear in the *Observations and Data Abnormalities* column. Learners receive no hints or other help of any kind at this point. They can move forward to the *Lab Data* interaction at any time they wish, and can return to this window at any time. They are not required to use any of the information presented in this window. In studies involving students' reactions to the Pathfinder, and its effect on learning, this particular aspect of the interaction has received very little mention or attention. However, we know that students use information from this window because data from the History inevitably appears in students' solutions, and data from the History is almost always relevant to successfully interpreting the laboratory data.

After relevant findings have been recorded, students progress to the *Lab Data* window (Figure 3), where they are required to identify abnormal data (reference intervals are provided) using a pull-down menu (e.g. normal, high, low) and then must type in the abnormality name (eg, anemia). Abnormalities are required to be spelled correctly, and a hidden dictionary enforces correct spelling. If a learner spells a term incorrectly three or more times, a button with the caption *Show Me* appears, and the learner can opt to see the correct spelling of the term, which s/he then types into the corresponding name field. Help menus are available to assist when needed. Data abnormalities are identified with a "D" as they appear in the Observation and Data Abnormalities column. The *Lab Data* window is the interaction that provides most of the information that will be considered in arriving at a solution. In addition to requiring correct spelling, this interaction requires that the learner identify all abnormal data before progressing to the next interaction, which is to construct their diagnostic rationale in a format that we call a "diagnostic path."

Some observers of the Pathfinder have been critical of several aspects of this interaction. The requirement of typing each abnormality name using the correct spelling is the least popular feature of the software with students. Similarly, this feature has been criticized by observers for various reasons, including: a) spelling is something a computer can do; let the computer fill in the abnormalities itself, b) spelling is a lower-order thinking skill; how can students worry about higher-order thinking like problem solving when the software forces them to worry about spelling?, and c) what about learners with learning disabilities such as dyslexia for whom spelling is particularly difficult? At the core of our response to these reasonable concerns is that we designed the software to mimic the real world. In a real world setting, laboratory data is often presented without correct (or any) spelling of the resulting data abnormalities. While this is changing, we did not want to omit a key potential source of cognitive load in our simulated environment that would likely be present in a real environment. Similarly, in conversations regarding cases, students are more likely to be able to engage in real meaningful conversations regarding underlying concepts if they have mastered and are comfortable with the vocabulary. Otherwise, they are likely to lose opportunities for higher order learning because they cannot remember if *anemia* refers to red or white blood cells. Practically speaking, our studies have shown that students perform better on case-based exams after using the Pathfinder than after using other strategies that do not require correct spelling (Danielson et al., 2003; Danielson et al., in press); furthermore, students, while they can become annoyed with this feature over time, often mention that it helps them learn the medical vocabulary (Danielson et al., in press).

Observers have criticized the feature of this interaction that requires identification of all abnormal data. Veterinary observers correctly point out that (a) most lab print-outs automatically flag abnormal data, so clinicians don't typically have to hunt for it and (b) it is possible for disruptions in normal physiology to make normal findings appear abnormal or vice versa. Therefore, simply identifying all abnormal data will not necessarily provide all necessary information for solving the diagnostic puzzle. The latter concern can be translated into a broader context than medicine. Essentially the concern is that by requiring students to identify all abnormal data, the software might lull them into the incorrect assumption that they have identified all the factors that must be considered, or that all the factors that they have identified are relevant to solving the case. One final concern with this feature is that because one of the primary challenges of problem solving is to identify the appropriate information for solving the problem, the software might be spoon-feeding relevant information to the learners. Consequently, learners might be unable to identify relevant information when this feature is not in place in future problem-solving contexts.

Again, perhaps the best response to these concerns, considered together, is that a number of studies have shown that students who learn to solve problems in this fashion are more effective at solving similar problems without the benefit of the Pathfinder, than students who have learned problem solving in a similar fashion, but without these requirements in place (Danielson et al., 2003; Danielson et al., in press). Why is this so? Our studies thus far reveal that the key to leveraging these requirements in a way that benefits learning is found in the next two interactions – namely, the fact that learners must explain, in some way, all the abnormal data, and the fact that they are provided with an expert explanation to consider. This will be discussed in greater detail when we discuss the next interaction – the *Construct Diagnostic Path* interaction.

Once all data abnormalities have been identified, students proceed to the *Construct*

Diagnostic Path window, where data abnormalities are organized into groups and assigned a series of causal mechanisms. This powerful and flexible environment supports the non-linear reasoning process needed to organize and interpret data. History and data abnormalities are dragged from the Observations and Data Abnormalities list on the right into the drag-and-drop workspace on the left, where they are grouped under causal pathophysiologic mechanisms (designated by “M”) (Figure 4). Clusters of mechanisms and/or data then are further organized into a hierarchical, indented outline that provides a visual representation of the diagnostic reasoning or rationale (Figure 5). The resulting outline is called a *diagnostic path* and provides the rationale (student or expert) explaining the data. Items above and to the left cause items below and to the right; or, items below and to the right provide supporting evidence for items above and to the left. Observations and data abnormalities may be included under multiple mechanisms or may be used as supporting evidence for multiple mechanisms. In other words, multiple hypotheses may be formed for any of the various data abnormalities. All components of the diagnostic path can be rearranged at will. Item clusters (groups of mechanisms with supporting data) can be expanded and contracted using various keyboard and mouse techniques. A free-text note can be linked to any item, to explain the diagnostic reasoning in greater detail (Figure 6). The Construct Diagnostic Path window requires that all observations and data abnormalities be used in the interpretation process and provides a uniform format to communicate that process.

Our research suggests that this interaction is critical to the success of the tool. Many students made comments to the effect that the Pathfinder helped them learn because they were “forced” to consider all data (Danielson et al., in press). Anecdotally, we have observed that when working through cases without the Pathfinder, students have been perfectly comfortable obtaining a diagnosis through intuition, and then simply ignoring the data that did not support that diagnosis, leading them down the wrong logical path, and ultimately culminating in frustration. This is considerably less prevalent in solutions that involve the Pathfinder. We believe this is so because the software requires students to include all identified abnormal data in their diagnostic path. Note that “inclusion” does not imply that all data are relevant to the solution. In fact, often data are included under headings such as “clinically insignificant.” Although students can create any solution they want, and could, theoretically, create a category called “data I am choosing to ignore,” this isn’t something that they tend to do. The software forces them to *include* all the data they identified in their solution, and they force themselves to *consider* it all. Sometimes, after consideration, they deem certain data to be insignificant, falsely high, or falsely low, etc. – all of which shows up in their diagnostic path.

Other than providing an environment in which data can be manipulated relatively easily, the diagnostic path has no particular intelligence. It does not track user movements or provide any guidance or feedback.

Once the student has completed a diagnostic path and accounted for all data abnormalities at least once, the *Make Diagnosis* window becomes available (Figure 7). The diagnosis is also usually the top entry in the diagnostic path, so this step is simply formally submitting that mechanism as the diagnosis. The Pathfinder places little emphasis on the diagnosis itself, other than to record it. Students are asked to compare their rationale (diagnostic path) to the rationale (diagnostic path) of the expert – not just their diagnosis, as will be discussed in the next paragraph.

After entering a diagnosis, the student may proceed to the *Expert Diagnostic Path* window (Figure 8), in which their diagnostic path is displayed alongside that of the expert (one created by the instructor or some other expert pathologist) for comparison. The expert list is color-coded by the instructor who created the case in terms of core mechanisms (green, the main new concepts), review mechanisms (blue, practiced in previous cases), or framing mechanisms (black, concepts not central to the instructional objectives but which provide meaningful context). Students identify this interaction as being very important for supporting their learning (Danielson et al., in press). Perhaps in order to understand why this would be, it is important to know what this window is not: (a) This window is not an adaptive interaction. All learners see the exact same expert path. (b) This is not an interactive window. The expert path is static. Why, then, do learners find it to be so meaningful? Feedback, of course, has been shown to be meaningful in many instructional contexts, so its value should come as no surprise in this case. However, with regards to the specifics of this feedback, we would suggest that, just as the *Construct Diagnostic Path* interaction does not require a thoughtful integration of data, but invites one – the expert path does not require a thoughtful reflection on the learner's own rational, but invites one. We believe that this is significant, and may contribute to the design of similar tools, even intelligent ones, as discussed in the following paragraph.

We have chosen work by Kolodner, Owensby and Guzdial (2004) to illustrate how this principle might apply because they articulate the problem so effectively; this issue is likely to be identifiable in other work as well. These authors described Case Based Reasoning (CBR) theory, and a family of CBR-based learning tools that were designed to help students learn complex skills. Like cognitive apprenticeship, CBR emphasizes the value of authentic experience in learning and knowing. Experience is encoded as cases, with case indexes and a case processor accessing and providing relevant cases to the problem solver as needed. Learning tools based on CBR engage students in authentic problem solving activities, and provide relevant cases (stories) for learners to access throughout the problem solving process. These are *intelligent* tools. Prompts are frequently integrated to provide suggestions to students as they move forward, or to suggest ways in which they might gain the most benefit from a specific case. The authors showed these tools to be useful both for learning and for designing learning cases. While these approaches have proven to be very successful, Kolodner et al (2004) assert that, “computer tools can aid reflection, but the wanting to reflect, helping learners reflect better, and managing when to reflect have to be handled from elsewhere. (p. 834)”

Our experience with the Diagnostic Pathfinder, however, suggest that learners, by interacting with the Pathfinder, naturally pause to reflect at two key points – when they seek to integrate all data into the diagnostic path, and when they consider the expert feedback. The tool does not explicitly prompt reflection, nor does it require that students pause any longer than to click a button. However, the tool’s inherent functionality prompts both the desire to reflect and the timing of reflection. Learner feedback suggests that these are the most meaningful elements of the case analysis for learning.

Once the student views the expert list, the Submit for Credit window is made available (Figure 9). This allows students to gain course credit for completing the assignment and also provides the opportunity for self-assessment. Students are asked to indicate the degree to which their own path agreed with the expert path. This self-assessment does not contribute to the grade, but is intended to help the instructor identify topics (cases) that proved problematic to a number of students. Should a student not be ready to submit a case for credit, partially completed cases may be saved to a server database and/or locally for access at a later time.

The Pathfinder has an Administrator Mode that allows instructors to view individual student diagnostic paths, view student self-assessments, identify cases submitted for credit, and modify existing expert paths. In addition, the Pathfinder has a Presentation Mode that displays the screen through computer projection and allows the instructor or presenter to gradually reveal portions of the diagnostic path as they explain or work through the case.

Faculty Response to the Pathfinder

Over the past ten years, the Pathfinder has been used by a number of faculty to teach diagnostic problem solving. The purpose of the present study is to characterize the Pathfinder and its impact from the perspective of those faculty.

Method

Participants

Faculty members who used the Pathfinder to teach clinical pathology between 2002 and 2007, and residents (also referred to as "faculty" in this study) who were assisting them in their teaching, were invited to participate in an interview regarding their experience teaching with the Pathfinder.

Procedures

Faculty were interviewed using a flexible interview protocol, with most interviews occurring over the phone. All faculty members (n = 9) were interviewed during and/or at the conclusion of their first year using the Pathfinder. Additionally, three of the original interviewees, who are all course leaders, were interviewed after having used the Pathfinder for at least 4 consecutive years. Interviews occurred over a period of 5 years. Interviews that occurred directly following the first year of teaching focused on determining the usability of the Pathfinder, the feasibility of its implementation, and the perceived impact on learning. The interviews that were conducted after four years of use focused on determining faculty perception the Pathfinder's affected on their students' learning. The interviews were analyzed using an open-coding process, which produced a number of common themes. Themes which were no longer relevant (such as technical issues that had been resolved) were not included in this discussion.

Results

Real Life

Many (6) faculty identified the importance and benefit of the way in which the Pathfinder makes the information that is being learned more real to the students. Faculty referred to this phenomenon using phrases such as putting "facts into application," "doing something with the information," "simulating reality," "real life exposure" and "teaching clin path the way it is used in practice." Clearly this referred to the fact that the Pathfinder employs realistic cases involving the kinds of scenarios and patients that are seen by practicing veterinarians. Several interviewees noted that, when using the Pathfinder, students were not just memorizing for the sake of memorizing, but seemed to be learning the information more purposefully, and implied that the realness of the cases contributed to the deeper learning.

Several faculty members also mentioned the way in which students are exposed to the reality of multiple ways of interpreting a case. In several instances students were exposed to expert diagnostic paths that were authored by someone other than their course instructor, or were exposed to other students' completed paths. Faculty indicated that it was good for students to be exposed to the reality that there is more than one way of interpreting or explaining clinical laboratory data for any given case. In one interviewee's words, students were able to see that the case explanations are not "black and white."

Keeping up

The Pathfinder provided faculty with a way to make sure that students worked consistently than rather than in last minute spurts such as is associated with cramming. In most settings, Pathfinder cases were assigned as homework, and credit was awarded for simple completion of the case. Often, prior to implementation of the Pathfinder, there had been a case-based homework requirement, but faculty gave the impression that students complied better when using the Pathfinder. In one interviewee's words "keeping up is imposed." Similarly, faculty noted that the Pathfinder allowed for a lot of repetition, using phrases such as "lots of repetition", "lots of cases" and "multiple examples." One interviewee noted that aspects of the repetition could become tedious for students, and prior studies support the fact that at times students felt overwhelmed by the amount of work. However, faculty also made comments to the effect that keeping up by way of the Pathfinder was more beneficial and palatable to students than other traditional forms of study. In one faculty member's words, students who used the Pathfinder, "say that they don't have to study."

Thinking Better

Faculty reported that the Pathfinder helped the way their students thought about clinical pathology. Several simply observed that students, as a result of Pathfinder-use were better than students from previous years at interpreting laboratory data, thinking about mechanisms behind laboratory data changes, or understanding/recognizing the pathogenesis (cause, development, effects) of disease processes. Faculty implied that this was the case because the Pathfinder process encourages this understanding, and supplied a number of specific reasons that this was so. They discussed two main themes: **the process of creating the diagnostic path** and the way in which Pathfinder use **enhanced communication –** between learners, among instructors and learners, and among experts.

The Creative Process

In constructing a diagnostic path, students use it to "really integrate" the information which in one respondent's words created, "a rich context of cause and effect." The drag and drop feature of the Construct Diagnostic Path window itself was seen as being important. One of the experienced interviewees, referred to the ease of being able to just "plunk" abnormalities in the diagnostic path, and easily move them around. This process of diagnostic path creation was likened by another experienced interviewee to "an artist sitting there making a painting." In describing her own diagnostic path creation, she noted that, "you want to make it a work of art – a pretty picture," and she reported finding about twice as many relevant mechanisms in any given case while using the Pathfinder than if she were not using it. To these faculty, this artful and detailed manipulation of data would not be possible using a piece of paper and a pencil or a word processor.

The diagnostic path format was also mentioned by several as being powerful because it could be flexible in terms of the depth with which a topic could be treated, and the contexts (types and levels of cases) which it could accommodate. The path format is not limited in terms of the detail which can be used. Beginning students can create accurate and coherent paths that deal with disease mechanisms at a relatively superficial level. More advanced students can dig deeper into each mechanism, communicating down to the molecular level if appropriate.

To several respondents, the creative path construction process was fueled by the requirement of using all laboratory data. Students could only learn to make sense of the full data set if left to struggle with all of the information at first, learning through experience how the pieces fit together. One respondent offered the differing view that students needed more guidance at the beginning regarding which data were relevant and which were not, and should only be required to consider “relevant” data. One could easily argue however that normal data is in fact “relevant” in that it rules out other diseases or conditions.

The most frequently mentioned difficulty with Pathfinder-use involved the diagnostic path as well; for many cases, there was far too much information to “fit” comfortably on the computer screen. Diagnostic paths are likely to run several screen lengths and cannot all be seen at once without being collapsed.

Finally some respondents mentioned the Pathfinder as a “safe” learning environment. Students could focus on the case in an environment free of criticism, in which mistakes would be tolerated and in which they were relatively anonymous. This is an environment without, as one respondent put it, “a clinician breathing down [the student’s] neck.” Another respondent mentioned the importance of students being able to work through cases “at their own pace” rather than being hurried or pressured.

The instructors’ primary concern about the Pathfinder’s effect on learning was that the problem solving experience was not complete enough. Most commonly, respondents wanted students to have the opportunity to select laboratory tests (something that the clinician does in practice), rather than simply interpreting the data from the already selected tests. Instructors also mentioned that because cases are frequently tied to specific lectures, the context of the case can guide students’ conclusions (though one instructor noted that this is “appropriate”).

Enhanced Communication

Using the Pathfinder enhanced communication. One respondent mentioned students’ diagnostic paths being detailed and “express[ing] clinical reasoning beautifully.” Another respondent reported better understanding students’ “stages of learning” and their mistakes. Another remarked that the Pathfinder makes the case/interpretation explicit; she used the Pathfinder to quickly review student homework solutions right before lecture, uncovering “all kinds of misconceptions” regarding points that she previously thought were “clear.” For misconceptions that were shared by many students, she would then review those points in class. This sort of review was possible because the diagnostic path “tells a story” and “presents logical and orderly thinking.”

If the Pathfinder makes the learners’ reasoning clearer to the instructor, instructors also credited it with making their reasoning clearer to the learners. Respondents reported that learners greatly valued the opportunity to see how their instructors would explain the pathophysiology of a case. One faculty member likened the Pathfinder's process and feedback to letting students "crawl around inside [her] head," and said that concepts that were difficult to communicate prior to using the Pathfinder were now "just there." The Pathfinder, according to the respondents, also helped their students learn the medical terminology. Because medical terminology forms the "elements" of the conversations regarding each clinical case, understanding those elements' meanings would enhance communication.

Several respondents reported that using the Pathfinder made their reasoning clearer to *themselves* and to *other experts*. In one respondent's words, the Pathfinder forces the expert to "come face to face with their own idea of mechanisms" and "uncover misconceptions." Another respondent reported that years of Pathfinder use had made her expert explanations "much less sloppy" and had improved the precision with which she thought about the underlying mechanisms of disease. Sharing expert paths caused another respondent to note the need for "more consistency among experts." Another reported that, while demonstrating the Pathfinder to a group of experts at a conference using a very simple demo case, she was surprised when one well-known expert's input was to disagree with the case's expert solution. These experiences highlight the fact that in the domain of clinical pathology, there has not been a common mechanism or format for explicitly communicating relationships among data. For those who use the Pathfinder, the rather loosely articulated "problem list" is beginning to be replaced by the more structured and consistent "diagnostic path."

Several faculty reported that Pathfinder use had beneficially affected their students' attitudes about diagnostic problem solving. One reported that students were "more excited about interpreting clinical laboratory data," -- another that students now recognized "the importance of problem solving to the course."

Course Management

The Pathfinder affected the nuts-and-bolts management of the instructional enterprise. On the negative side, technical problems, which were somewhat more plentiful in early years and nearly eliminated in later years, contributed to the instructors' workload, and to students' general angst. Acclimation to the Pathfinder took instructor time, and in some cases called for infrastructure (computer projection equipment or laboratory computers) that were not fully in place when the Pathfinder was first implemented.

The Pathfinder also facilitated desirable course management activities. Respondents mentioned the benefit of students being able to work on cases anywhere, the fact that the Pathfinder provides an easy way to award credit for work, and that it provides an easy way to provide feedback.

Conclusion

There are many lenses through which any given instructional intervention might be viewed and explained. Our approach has been to make connections between our work and current relevant theoretical ideas, without claiming a specific theoretical pedigree. For example, when first describing the Pathfinder (Danielson et al., 2003), we framed the results briefly in terms of the then-current discussion of medical problem solving, cognitive apprenticeship, and constructivism, and have more recently discussed the

Pathfinder in terms of cognitive load theory and cognitive tools (Danielson et al., in press). Our primary interest has been in describing what has worked, and what has not. We do not devalue theory, but wish to avoid missing important nuances by lightly placing this or any other work in a constrained theoretical box.

In our first discussion of the Pathfinder (the *Problem List Generator* at the time) (Danielson et al., 2003), we drew two important implications – first that it is beneficial for the information that will be synthesized during the problem solving activity to be identified prior to the synthesis activity, and second, that it is beneficial for both expert and learner to use the same format for solving the problem and communicating the solution.

Our second exploration of the Pathfinder confirmed the initial findings (Danielson et al., in press) and contributed more detail. Specifically, we concluded that the Pathfinder's gating features – including the requirement of "sequence" (identify data before synthesizing it) and "completeness" (accounting for all abnormal data) contributed to the learning of problem solving. Specifically, the "completeness" requirement appeared to harness the learners' internal motivation. We also concluded that obtaining feedback (comparing ones rationale to another's (expert) rationale) seems to be a critical component of constructing and manipulating the learners' model of the system. We argued that these functions of the Pathfinder made it a cognitive tool for learning diagnostic problem solving.

The Pathfinder as a Cognitive Tool - Revisited

The data presented herein support what we have discovered previously, and they provide important contextual information that expands the conception of the Pathfinder as a cognitive tool in the domain of clinical pathology.

Playing it Safe

Several comments suggest that veterinary curricula do not always provide "safe" opportunities in which to address problems. Undoubtedly, in our anecdotal experience, there is, in this setting, a stigma attached to being "wrong." Therefore, perhaps one simple but powerful role played by the Pathfinder has been to provide a safe place to make mistakes. Students can tangle meaningfully with case information, try out various theories, and see the results – all without fellow students, or an instructor "breathing down their neck." This aspect of the Pathfinder, which highlights one aspect of the veterinary education setting, had previously gone unnoticed by us in our explorations of why the tool works. While this explanation is unlikely to fully explain the Pathfinder's success (other "comparison" practice environments were also relatively safe), this likely affects student comfort and creativity while dealing with instructional problems.

It's all about Communication

We knew in 2003 (Danielson et al.) that the Pathfinder aided communication between learner and instructor. This study helps to explain why. It is clear that, within their own teaching prior to implementing the Pathfinder, some of the instructors were not using precise and consistent formats for communicating the relationships among laboratory findings and mechanisms of disease. This is evidenced by the fact that these instructors found that Pathfinder-use made them less "sloppy" than they had been before. However, in these conversations, an even more interesting phenomena has emerged. Not only do faculty credit the Pathfinder with improving instructor-student communication, but they credit its use with actually clarifying their own understandings of their domain. This has happened as inter-institutional use prompted expert- to expert communication, revealing inconsistencies in the way that various experts view the same disease processes. However, clarification of their own understanding has also occurred as instructors have used the Pathfinder format to prepare explanations for students, independent of any discussions with other experts. The Pathfinder requires a precision and completeness that discourages "glossing over" troublesome or ambiguous content or perpetuating unsubstantiated assumptions. It also provides an electronic setting in which a great deal of data can be considered nearly simultaneously. Of course the Pathfinder does not do away with the limitations of human memory. It does however provide an environment in which it is relatively easy (much more feasibly than it would be on paper) to manipulate one or two mechanisms, put them aside to focus on a few others, and then return to revisit and manipulate the original ones again and again, experimenting with various arrangements of mechanisms and data abnormalities until the flow of the diagnostic path expresses the pathophysiology "story" to the satisfaction of the author. Expert solutions can be reviewed by the author and colleagues, updated, saved, and re-manipulated over the course of several years until all of the inconsistencies and ambiguities are removed. In summary, experts created more detailed, precise, and accurate understandings of disease processes when they used the Pathfinder because it, 1.) made their understandings clearer to others, 2.) made their understandings clear to themselves, and 3.) provided an electronic environment in which they could manipulate all the data they needed to arrive at the solution.

Implications, Applications, and Directions for Future Research

Do these findings have implications for other domains? Clearly, one of the reasons the Pathfinder had the impact on communication and reasoning that it did with the experts we surveyed was that there was a deficiency (at the least, a lack of standardization) in the way experts in this field communicated their knowledge with each other. Perhaps no similar effect would be seen in fields where ways of formally and precisely communicating knowledge are already in place. What our experience seems to illustrate, however, is that, consistent with the idea of a Cognitive Tool, the tools we use to deal with problems in any given domain, can actually affect the ways in which we go about understanding the domain.

This chapter began with a discussion of problem solving, and so we return to problem solving. Our goal, we asserted, was to help learners become better at solving diagnostic problems. Prior studies suggest that we were successful, but why? The challenge of teaching problem solving, we asserted, is that to teach someone to solve problems is to teach them to deal, to a certain extent, with the unknown. Perhaps, at the end of the day, the Pathfinder helped learners in several important ways. First, it encouraged precision and consistency in communication – both between instructor and learner, and between the problem solver and him/herself. Second, it helped the problem solver keep track of the large amount of information that must be processed to solve a complicated case. Finally, it interacted effectively with the social environment in which it was placed – first by requiring a precision and level of standardization from experts that exceeded what they were typically accustomed to, and second, by requiring the same of learners. Additionally, the Pathfinder provided an electronic world for learning to problem solve that was safe for experimentation, failure, and growth.

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Figure Captions

Figure 1. Case Selection.

Figure 2. Signalment, history, and physical examination findings.

Figure 3. Laboratory data interaction.

Figure 4. Diagnostic path constructor window.

Figure 5. Diagnostic path.

Figure 6. Diagnostic path note.

Figure 7. Make diagnosis.

Figure 8. Expert diagnostic path.

Figure 9. Submit for credit.