Mapping and Validating Case Specific Cognitive Models

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Abstract: This study proposes a visual methodology to validate complex solution processes in the context of ill-structured problem solving. This experiment is anchored in the context of medical case-based teaching. The case validation activity proposed is modeled on the authentic case presentation practice performed by physicians. We are using a computer-based learning environment (BioWorld) to present a standardized set of cases to expert teachers who are asked to solve the case and do a think-aloud protocol while solving the cases. We are developing a methodology that addresses both knowledge elicitation as well as knowledge validation for solving and reflecting on ill-structured medical problems. More precisely, this study examines the effectiveness of visual support tools to help physicians verify their diagnostic thinking. In so doing our goal is to build and validate case specific cognitive models.

Introduction

Problem based learning (PBL) is not a new approach in medical education, it is used to teach clinical reasoning and problem solving skills in a number of medical schools (Barrow, 1994; Barrows & Tamblyn, 1980; Koschman, Kelson, Feltovich, & Barrow, 1996). The use of cases for teaching is as old as storytelling and Cox (2001) argues that this way of transmitting knowledge provides a meaningful framework to embed all the objectives and sub-objectives related to a complex patient case. A case presentation in medicine generally consists of a detailed analysis of a patient case but depending on the instructor's prior experience and the facilities in which the patient is seen the solution to these cases varies substantially. Case development work for BioWorld (a computer-based learning environment (Lajoie, Lavigne, Guerrera, & Munsie, 2001)) led us to note significant differences in the thinking and decision making processes involved in complex case solution. Data on the case creation phase demonstrated both validity and reliability issues when working with medical staff and students. This lack of consistency forced us to address the issue of validity and reliability of ill-structured solutions in a more systematic manner.

Case presentation activities are used to teach diagnostic reasoning. Diagnostic reasoning about patient cases share the same components of ill-structured problem solving as defined by Jonassen (1997) in that solving patient cases involve a) plenty of unknown elements, b) there is not one correct unambiguous solution, c) there is more than one way to reach a diagnosis and there are usually multiple ways to reach an acceptable answer (often referred as differential diagnosis) c) there is no absolute criteria or way to validate the answer, and d) case resolution often involves ethical and personal judgments.

This research aims at modeling and building on the case presentation activity that occurs in medical education. We do not intend to replace or compete with the face-to-face case presentations but it aims at documenting and building on key elements related to this practice. In this paper we first describe the instructional context and the computer-based learning environments we use to support and study diagnostic reasoning. We then explain how the validation activity became a key element of the case creation process. We also explain why and how the sampling of detailed solution processes and explanations of expert teachers can lead to the construction of cognitive models.

Cognitive tools to support and study diagnostic reasoning

BioWorld, is a computer-based learning environment that was first designed to promote scientific reasoning in high school students. It provides a realistic environment for students to learn about diseases through solving specific patient cases (Lajoie et al., 2001). Solving a patient case in BioWorld not only consists of submitting a good diagnostic but it also requires students to select and organize evidence that supports and justifies decisions through the case resolution process.

Pilot work with medical students, residents and staff physicians was conducted using BioWorld cases and conclusions recommended the use of this learning environment for medical education (Faremo, 2004). One key aspect of adapting BioWorld to a medical audience is to revise and construct cases at an appropriate level of difficulty. In our attempts to create and develop valid cases in medical education, we have experimented with different methodologies and scenarios to structure case creation. The companion authoring tool, CaseBuilder (Lajoie et al., 2001) which was designed to allow both instructors and researchers to modify cases easily also enables us to explore instructional activities for content creation and revision. Creating cases for an interactive computer environment implies documenting not only the questions and information related to the acceptable answer but it also requires the inclusion of plausible distracters or possible questions learners might have while trying to solve the case.

Creating a case can also be referred to as a problem generation activity, which is an instructional technique that requires the learner to assemble or construct a problem. In a problem generating task the learner needs to choose a specific case to construct or modify the problem they choose to explore and analyze if all the elements are defensible and could make sense for potential problem solvers. Silver (1994) includes both problem modification and problem construction in his working definition of the technique. The problem creator has to make sense of a situation and determine which elements can contribute to the solution and which other elements need to be present as distracters to increase the level of difficulty of the problem. In this context the case builder becomes a cognitive tool that supports our exploration of this learner-centered knowledge building activity.

Our data on the case creation phase demonstrated both validity and reliability issues when working with medical staff and students. As we raised the level of complexity of the cases in BioWorld we encountered challenges in the design and validation of solutions for these complex cases. As mentioned above, the solution to a case in BioWorld does not only consist of the final answer but it also requires a list of prioritized supporting evidences related to this answer. Consequently in the case creation activity, when medical students were constructing cases they had to provide and list the evidence supporting a good diagnosis. We found discrepancies between their hypothetical answer (answers they had planned) and their actual solution (the one recorded when they ran through the case in BioWorld). We first hypothesized that students were maybe not qualified enough to provide a clear answers so we asked a medical expert to do the same case twice. The expert was not aware of having to solve the same case twice; patient names were changed, a 10 day delay between testing occurred and we presented the expert with other similar cases in between the two cases in question. Again we obtained non-identical answer for a relatively simple case of diabetes. Our last attempt to address the inconsistent supporting evidence was to ask a second medial expert to do the exact same diabetes' case. Results were consistent with our two previous experiences and this lack of consistency forced us to address the issue of validity and reliability of solutions in a more systematic manner.

Tracking expert solution processes and explanations

To address the variability of the case's solutions we decided to construct a case validation activity. The simple list of evidence for justifying and explaining the answer was not sufficient to show where and how expert differed in their problem solving processes. Therefore the validation activity was designed to scrutinize every step along the way by including think-aloud protocols of individual participant. We justify this investment of time and resources by using expert teachers that have the ability and experience to solve and explain theirs though processes to others. Additionally, the validation activity has revealed itself to be a key component of the case creation process. The activity provides motivation and feedback to the medical student who acts as case creator. On the other hand when teachers solve cases created by students it gives them clear examples of students' misunderstanding of content and interrelationships of the different components involved in the diagnostic of cases. The validation activity consists of a simulation of a case presentation for medical teachers. Participants are asked to think aloud (do a think-aloud protocol) and provide explanations as they solve a case in BioWorld. The level of the cases and their explanation is at the undergraduate level. From a research perspective, we want to capture and record the strategies experts use to synthesize the information about a disease as well as how they structure and communicate this information in both oral and written forms. Expert teacher can provide us with relatively clear "path" of the decision process as well as explanations and verbalization about the metacognitive strategies they use while solving the cases. This validation activity will be used as a blueprint to build a cognitive model for each of our cases.

Sampling individual and collective problem representation

Protocol analyses are used to explore domain knowledge, to describe what are key elements and how knowledge is structured and used during a problem-solving task (Ericsson & Simon, 1993). Whereas protocol analyses of well-defined problems can result in clear problem solving sequences the analysis of ill-structured problems can be more complex given there is more then one way to reach a solution. We do not aim at conducting an exhaustive task analysis of all the possible solutions path or options but to sample and represent two to five solution paths for each case. The goal is not simply to build an expert path and use it to compare to novices' performance but to build a partial problem space representation that can evolve as more people do theses cases. The visual representations are built to offer a short summary of the though processes with the relative importance of specific steps to the resolution of the case. When interacting with theses representations participants can "zoom in" and open sub-layers to access details, related explanation and exact verbal transcript from the verbal protocol.

The problem space is constructed in three phases. The initial representation built by the researcher summarizes the decision-making process. It is used with experts to have them validate and reflect on the resolution path of the problem. We ask expert to first validate the summary of their case resolution and then select and categorize section of their decision path. Experts are asked to select which elements are absolutely necessary to the case resolution, which ones are necessary and which one adds useful information. The second version incorporates the changes and categorization done by the experts. This categorization of decision path reveals the relative weight of specific steps and facilitates a comparison between experts. In the third version of the representation we merge experts path to show similarities and differences in the sequence of decisions leading to acceptable answer(s) for a specific case.

Goal and purposes of the visual representation

This validation activity serves multiple purposes. The visual representation is a tool to build and to communicate partial data to participants. As our initial participants are expert medical teachers we hope to extract pedagogical models for teaching specific cases and not only experts' case solution processes. Their experience teaching concepts related to each cases and their ability to predict what learners at the undergraduate level can understand will help us validate and improve content. The actual visual representation could also be incorporated into the computer-based learning environment to teach students. However we hope to use these qualitative blueprints to implement better scaffolding and feedback mechanism into our computer-based learning environment.

Situating the methodology

The use of a diagram, for the partial analysis of data is not a common procedure but Henderson, Yerushalmi, Heller & Kuo (2003) have found that visual maps are useful to analyze complex interview data. They found that concept maps reflected participants' conceptual understanding of the topic, clearly showed relationships between concepts and were useful to show similarities and differences between participants. The use of the term 'concept map' by these authors can be misleading as they do not use it in the way Novak and Cañas (2006) describe in their work. Henderson, Yerushalmi, Heller & Kuo used the Cmap software as a knowledge visualization tool to provide a visual overview of their protocol analysis. The diagram is not constructed by the participant but by the researcher from the verbal protocol. We chose Henderson et al.'s technique as a starting point to develop our own methodology to show a clear link between raw data and the participants' conceptual and procedural knowledge while solving a case.

Pilot Study

Participants

Our subjects were two medical teachers from the medical school at a Canadian university. One subject was an internist and the one was a gastroenterologist.

Materials

Questionnaires and case index

Participants were administered a questionnaire to control for their general practice, recent clinical experience and overall teaching experience. In a post-questionnaire we asked about their experience with cases related to the one they had solved in this study. Participants rated the cases for the level of difficulty and complexity after solving each of them.

Cases

The three cases presented to participants were diabetes mellitus type 1, hyperthyroid and pheochromocytoma. Theses cases were developed around similar set of symptoms and patient characteristics. Patient cases have similar symptoms to force participants to compare and contrast competing differential diagnosis and allow researcher to compare the solutions.

Software

Cases were composed using CaseBuilder but BioWorld software was used to present the cases to participants. Transcription and coding was done using Transana (Woods & Fassnacht, 2007) and the visual representation was built using Cmap software (Novak & Cañas, 2006).

Procedure

Phase 1

Two participants solved three fictitious patient cases in BioWorld. This computer-based learning environment presents patient information interactively. The environment allows the participant to navigate the problem space yet it is structured enough to allow for sequential presentation of case information. The task begins with a problem statement that presents a patient case. The participant selects relevant information from the case information and selects an initial hypothesis and confidence level in their hypothesis. As participants go through the different phases of the case resolution by selecting evidence and ordering tests they are asked to think-aloud and explain their reasoning as if they were doing a case presentation to undergraduate students. After participants have completed each case the verbal transcript and computer log are chronologically combined into one protocol (see example in table 1).

Line	Transcript of Verbal Data		BioWorld Log Data		
…	**Transcript**	**Time verbal**	**Time BioWorld**	**Evidence**	**Action**
25	So ah then I guess I should underline the evidence that I have here?	:07:42:			
26	R: yep	07:47			
27	E: So age is important. And then she is on medication, it's very important to know what the medication is.	07:55	07:55	37 year old	add evidence
28	And then just the high blood pressure in a 37 year old is a-, makes you think commonest thing is still essential hypertension but you have to start thinking possibly of secondary causes especially if her blood pressure is really high.	08:07	08:08	medication	add evidence
29	OK uh, frequent headaches is a very important thing if you combine the frequent headaches with the episodes of flushing that really makes you think a lot of a pheochromocytoma.	08:24			

Table 1: Merging verbal transcript and computer log

The researcher uses this protocol to constructs a visual representation of the solution process. Each node or item on the diagram is linked to original statements or action from the protocol. Items can be regrouped or nested into main nodes if participants explicitly combine them or if they represent pre-identified elements/actions from the reasoning process. This visual representation is a summary of their transcript, yet the link to the original data is easily accessible by mouse-over as shown in this screen capture of figure 1.

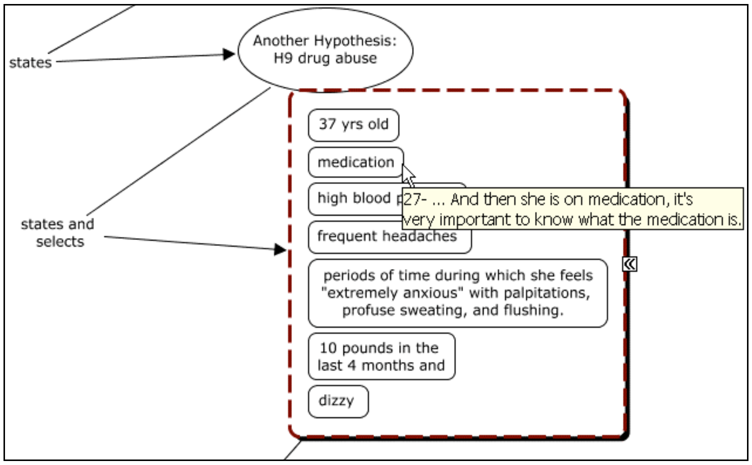

Figure 1: Extract of visual representation of the path with mouse-over

Phase 2

In phase two, a paper version of the diagram is presented to participants for validation. Participants can refer to the protocol and decide to modify or elaborate the initial diagram of their case resolution. Once participants have validated our summary they are asked to select which elements are absolutely necessary to the case resolution, which ones are necessary and which one adds useful information. In the activity participants are asked to color in red elements of the path that are absolutely necessary to solve the case; in yellow elements that are necessary to solve the case; and in blue extra information that is useful but not crucial for solving the case. This leads to a decision path to which we can assign weighting to selected elements. We chose to assign weights of 5, 3 and 1 to better differentiate the importance of each element and be able to use numerical values to assess solutions later on. The three points scale was used for practical reasons to differentiate items of relative importance. We may need to modify the categorization of this rubric if we find it difficult to apply to future sets of cases. Table 2 below summarizes the resulting grid. Figure 2 shows a section of the path that was categorized with colors in parenthesis.

	Red (+5)	Yellow (+3)	Blue (+1)
Key elements	Absolutely necessary (+5)	Necessary (+3)	Useful information (+1)

Table 2: Grid of weights for categorization of elements

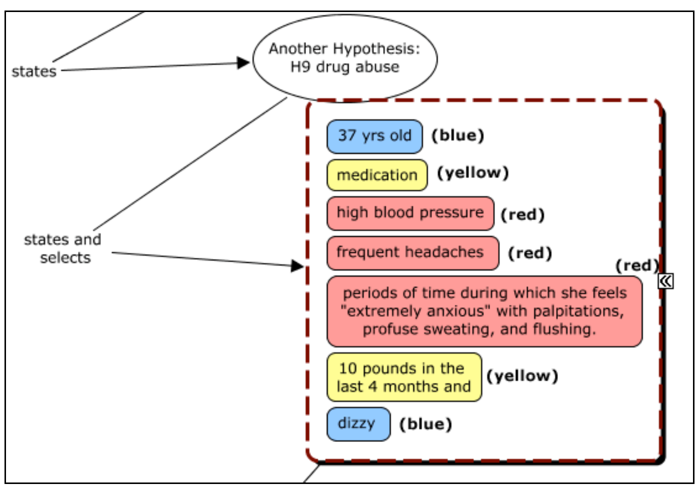

Figure 2: Categorized section of the path

Phase 3

In phase three the researcher combines the visual representation of both expert for each case. As seen in Figure 3 the representation shows where experts' decision process is similar and where it differs. Unfortunately the static figure does not allow the reader to explore details in each layer of the decision path but it gives a good overview of the representation.

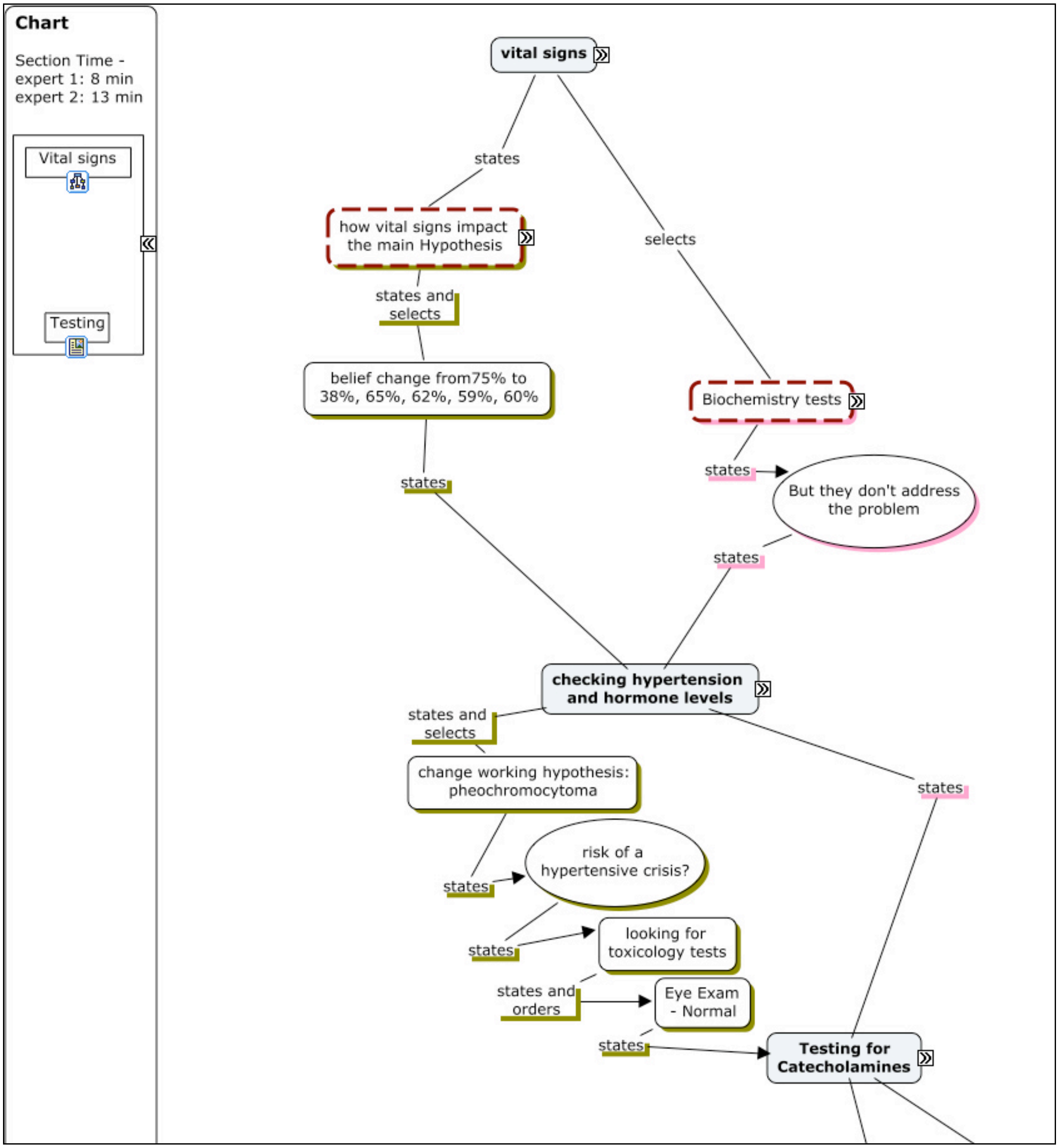

Figure 3: Section of the combined solution path

Preliminary Results

Visual representation of the problem space for each case

The use of multi-layers diagram allows for relatively simple overview of the reasoning process and it shows relationships amongst important elements of a case. It is particularly useful to capture details in the inner layers of the map as it is flexible in presenting peripheral information related to the case.

Exploring and explaining the variability of solution path

To explore and try to document and understand the variability of the solution path we will present sample of the results and analysis related to the case of Pheochromocytoma. The categorization of elements from the case resolution was used to explore consensus. Elements from the categorized diagram were sample from both experts into each of the three categories (red, yellow, blue – see annex I for detailed categorization tables). Table 3 combines the sum of elements for each category by each expert. As you can see the number of elements selected is similar (20 for expert 1 and 18 for expert 2). However when the weights are applied to the categorized elements as shown in table 4, the difference between our two experts is a lot more important (46 for expert 1 and 72 for expert 2). Expert 2 uses a higher weighting for most of the elements he selected which might be due to his experience teaching similar cases to students.

	Expert 1	Expert 2
Absolutely necessary	3	12
Necessary	7	3
Useful information	10	3
Total elements	20	18

Table 3: Comparison of the number of key elements from categorization tables

	Expert 1	Expert 2
Absolutely necessary (+5)	15	60
Necessary (+3)	21	9
Useful information (+1)	10	3
Total scoring	46	72

Table 4: Comparison of weigted elements from categorization tables

In table 5 we have combined element without taking categories into consideration to calculate the percentage of consensus between our two experts. This consensus rate is coherent with the literature in medicine.

Similar elements with similar weighting	8
Similar elements overall	13
Total of elements	38
Percentage of similar identified elments	34.21%

Table 5: Summary table

Exploring the resolution process

To better understand and categorize the reasoning process of our participant we use a coding scheme that was adapted from previous work in medical reasoning (Faremo, 2004). Elements of interest from our coding scheme fall into six main categories. We are analyzing time, diagnostic tests, interpretation of tests, hypothesis and confidence level, evidences and use of metacognitive skills throughout our sources of data. The three main sources of data are computer log and report, the verbal transcript and the categorization tables. We also have observational and questionnaire data but we consider them as secondary relevance for this research.

In brief, our initial analysis show a consistency in the number and specific evidence collected, the list of hypothesis generated (verbally and with computer log) and the time required for the formulation of the correct hypothesis. However we found differences in the number and list of tests ordered as well as the length and level of explanations.

Limitations and lessons learned

As this pilot study was used to test material and procedures we are confident that the real study will address some of the limitations identified throughout this experimentation. Careful selection of participants seems to be key since we are testing the pedagogical model and that our data show that one of our participant only had textbook kind of experience with these cases. Other lesson learned concerned the reduction of data manipulation and the inclusion of screen captures to improve the transcription phase and make our data more reusable. The use of pen and paper method with participants has been restricting so we will have our participants directly interact with the Cmap software in our next experimentation.

Conclusion

Ill-defined problems do not have clear-cut answers but contrasting optimal and not so optimal solutions might improve participants' fragmentation of the problem representation and meta-cognition. By carefully documenting the resolution of cases by participants we hope to gain an understanding of how scripts or schema develop for diagnostic reasoning (Charlin, Tardif, & Boshuizen, 2000) and explain the variability found in cases' solutions. We want to further explore if visual representations of solution paths can provide a meaningful framework to synthesize, structure and communicate different levels of knowledge, reasoning strategies and metacognition.

As more data are collected we will test the robustness of the methodology and add a developmental perspective to the problem space representation for each of our cases. The coding scheme developed needs to be validated with other participants. This step is a pre-requisite to allow for comparison of diagrams from multiple participants as described in other studies using visual knowledge representation tools (Henderson et al., 2003; Johnson, 2005).

Building cognitive model by consensus building

The main goal in sampling expert collective solution paths for each case is not only to explain variability but to reach consensus on what are the key elements for leading to successful or acceptable solutions. Building cognitive models will also include errors and strategies in the context of specific case resolution. The visual representation aims at being a source of information for researchers and experts for analysing diagnostic reasoning. Additionally the representation also provides learners and instructors in medicine with a meaningful tool to record and build on the case presentation practice. We are spending a great amount of time on expert pedagogical models to enable their use and test their utilities with cohort of students. The next step in our research will be to test these models and verify the accuracy of pedagocical models as captured by this activity.

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Annex I : Categorization Tables of Expert for the Case of Pheochromocytoma

E1	Absolutely necessary (+5)	Necessary (+3)	Useful information (+1)
1	**Urinary Catecholamines / Norepinephrine**	**high blood pressure**	**37 yrs old**
2	**Urinary Catecholamines / Total (Epinephrine + Norepinephrine)**	**extremely anxious**	not a new problem
3	**Urinary Metabolites / Vanillylmandelic Acid (VMA) 24 hr**	**palpitation, profuse sweating, and flushing**	Fasting Blood Glucose Level - normal
4		more frequent in the past little while	Serum Electrolytes / Anion Gap (Na-(Cl+HCO3))
5		**weight loss**	Serum Electrolytes / Magnesium (Mg)
6		Ultrasound / Abdominal Scan	Serum Liver Pancreatic Tests / Alanine Aminotransferase (ALT)
7		CT / Body	Aldosterone
8			Adrenocorticotropin homrone (ACTH)
9			Cortisol
10			Dehydroepiandosterone Sulfate (DHEA-S)

Table 1: Categorization of key elements of expert 1

E2	Absolutely necessary (+5)	Necessary (+3)	Useful information (+1)
1	headache, palpitations, sweating and flushing; makes me think of secondary causes of hypertension	medication	**37 yrs old**
2	pheochromocytoma is rare so you need to keep other causes in mind	**10 pounds in the last 4 months and (evidence)**	Dizzy
3	**high blood pressure**	checking toxicology tests	eye exam test
4	frequent headaches		
5	**periods of time during which she feels "extremely anxious" with palpitation, profuse sweating, and flushing.**		
6	hypothesis 1: Grave's disease		
7	hypothesis 2: pheochrocytoma		
8	hypothesis 3: essential hypertension with reaction to medication		
9	hypothesis 4: drug abuse		
10	pulse of 98 a minute		
11	**one of the 3 followint tests: a)Urinary catecholamines, b) Urinary Metabolites VMA, c) Urinary catecholamines**		
12	submit hypothesis pheochromocytoma with high belief		

Table 2: Categorization of key elements of expert 2