# Learning perceptual aspects of diagnosis in medicine via eye movement modeling examples on patient video cases

## Citation for published version (APA):

Jarodzka, H., Balslev, T., Holmqvist, K., Nyström, M., Scheiter, K., Gerjets, P., & Eika, B. (2010). Learning perceptual aspects of diagnosis in medicine via eye movement modeling examples on patient video cases. In S. Ohlsson, & R. Catrambone (Eds.), *32nd Annual Conference of the Cognitive Science Society (CogSci 2010): Proceedings of a meeting held 11-14 August 2010, Portland, Oregon, USA* (Vol. 3, pp. 1703-1708). Cognitive Science Society.

**Document status and date:**
Published: 01/11/2010

**Document Version:**
Peer reviewed version

**Document license:**
CC BY-NC-ND

**Open Universiteit**
**www.ou.nl**

# Learning Perceptual Aspects of Diagnosis in Medicine via Eye Movement Modeling Examples on Patient Video Cases

**Halszka Jarodzka∗, Thomas Balslev†, Kenneth Holmqvist‡,**
**Marcus Nyström‡, Katharina Scheiter∗, Peter Gerjets∗, & Berit Eika○**
∗Knowledge Media Research Center, Germany
†Viborg Hospital, Department of paediatrics, Denmark
‡Lund University, Sweden
○Aarhus University, Centre of Medical Education, Denmark

## Abstract

Complex tasks with a visually rich component, like diagnosing seizures based on patient video cases, not only require the acquisition of conceptual but also of perceptual skills. Medical education has found that besides biomedical knowledge (knowledge of scientific facts) clinical knowledge (actual experience with patients) is crucial. One important aspect of clinical knowledge that medical education has hardly focused on, yet, are perceptual skills, like visually searching, detecting, and interpreting relevant features. Research on instructional design has shown that in a visually rich, but simple classification task perceptual skills could be conveyed by means of showing the eye movements of a didactically behaving expert. The current study applied this method to medical education in a complex task. This was done by example video cases, which were verbally explained by an expert. In addition the experimental groups saw a display of the expert's eye movements recorded, while he performed the task. Results show that blurring non-attended areas of the expert enhances diagnostic performance of epileptic seizures by medical students in contrast to displaying attended areas as a circle and to a control group without attention guidance. These findings show that attention guidance fosters learning of perceptual aspects of clinical knowledge, if implemented in a spotlight manner.

**Keywords:** example-based learning; eye tracking; expertise; attention; medical education

With progressing technical development, complex visualizations are increasingly in use for tasks, such as interpreting weather maps (Canham & Hegarty, 2010), classifying fish locomotion (Jarodzka, Scheiter, Gerjets, & Van Gog, 2010), driving (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003), or air traffic control (Helleberg & Wickens, 2003), to name just a few diverse examples. Dealing with such tasks requires not only knowledge about facts in this domain (i.e., conceptual knowledge), but also substantial visual search (i.e, perceptual skills). Sophisticated perceptual skills enable people in these professions to rapidly perceive the relevant out of the irrelevant and interpret it correctly. A large body of research has already shown that experts exceed novices in those skills (e.g., Antes & Kristjanson, 1991 ; Canham & Hegarty, 2010 ; Charness, Reingold, Pomplun, & Stampe, 2001 ; Jarodzka et al., 2010 ; Underwood et al., 2003 ; Van Gog, Paas, & Van Merriënboer, 2005 ; Vogt & Magnussen, 2007).

## Perceptual Skills in Medical Education

The extensive presence of visually rich tasks and thus, the importance of sophisticated perceptual skills is especially true for the medical domain. Many medical imaging techniques developed only recent (like fMRI, CT, 3D displays). The task to diagnose medical images can also be seen as a visually complex task. In particular, since research could already show expertise differences on a perceptual level (e.g., Krupinski, 2005 ; Krupinski et al., 2006 ; Kundel, Nodine, Krupinski, & Mello-Thoms, 2008 ; Lesgold et al., 1988 ; Nodine, Kundel, Lauver, & Toto, 1996). However, not only diagnosing medical images is difficult from a perceptual perspective. Also the diagnosis in real-life situations of diseases that manifest in occasionally occurring behavioral patterns, like seizures, is difficult on a perceptual level (Balslev et al., in preparation). In the case of diagnosing seizures it is crucial to recognize the important features, which distinguish the seizure from normal behavior. Those features, however, might be short-term, subtle, time-sensitive, and not salient compared to other features.

Little children display many different movements. In rare cases some of these movements may be symptoms of diseases. In particular for small children that cannot be questioned it is important to carefully observe their movements for diagnosing certain diseases. The example we focus on are epileptic seizures. Epileptic seizures can be distinguished according to whether they involve one or both hemispheres of the brain ("International Classification of Mental and Behavioural Disorders (ICD-10)", 2006): if only one brain hemisphere is involved they are classified as partial seizures whereas if both hemispheres are involved they are classified as general seizures (here: spasms). Both seizure types have a normal behavior counterpart (i.e., differential diagnosis) with which they can easily be confused: epileptic seizures are easily confused with benign sleep myoclonus (BSM; Egger, Grossmann, & Auchterlonie, 2003), whereas spasms are easily confused with infantile masturbation (IM; Hansen & Balslev, 2009). A *general seizure* (spasm) is characterized by bilateral movements that can be spasmic or jerky, the face is affected, the infant briefly looses consciousness / awareness, and the movements are not stopped by touching the child. BSM is also characterized by bilateral, jerky movements, however, the face is not involved, the child is asleep, and the movements may rather worsen by touching the child. A *partial seizure* is characterized by lateral movements that can be spasmic or jerky, the face is affected, the infant looses briefly consciousness / awareness, and the movements are not stopped by touching the child. IM is also characterized by

lateral, rather tension movements, however, the face is not involved, the child is awake and conscious, and the movements stop by touching the child.

In order to convey diagnostic skills, medical education focused in its beginnings on the role of biomedical knowledge (Feltovich & Barrows, 1984 ; Kuipers & Kassirer, 1984 ; Lesgold et al., 1988). Biomedical knowledge is the knowledge contributing to the understanding of the functioning and dysfunctioning of the human body and gained during textbook or lecture study. It is composed of conceptual or factual knowledge. Thus, biomedical knowledge may be described as "inert knowledge". Knowledge is inert, if it is learnt in a formal setting and can be expressed by the student as facts without the ability to apply it in a real world situation (Whitehead, 1929). The focus on conveying inert knowledge in education has been extensively criticized by educational psychologists (e.g., Pozzi, Noss, & Hoyles, 1998).

In line with those findings, current research on medical education emphasizes that besides biomedical knowledge, also clinical knowledge is important (Boshuizen & Schmidt, 1992 ; Patel, Evans, & Groen, 1989a, 1989b ; Patel & Kaufman, 1995 ; Schmidt & Boshuizen, 1992, 1993). Clinical knowledge is composed of manifestations, classifications, and treatments of diseases and it is gained during clinical praxis. One important aspect of clinical knowledge may be seen as being of perceptual nature (Manning, Gale, & Krupinski, 2005). As described above, novices have severe deficiencies on this level. However, there is little research so far, focusing on this aspect of clinical knowledge (Chen, Gale, & Evans, 2009 ; Jarodzka, Gog, Dorr, Scheiter, & Gerjets, in preparation ; Litchfield, Ball, Donovan, Manning, & Crawford, 2008). Thus, the aim of the current study is to enhance the perceptual part of information-processing as part of medical expertise.

### Conveying Perceptual Skills by Modeling Examples

An approach that has recently been developed to foster perceptual skills are eye movement modeling examples (Jarodzka et al., in preparation ; Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009). To develop such modeling examples an expert model is recorded while performing a task. In addition, the model explains hers/his actions and hers/his eye movements are recorded. In a second step, those recordings are replayed to a student as an educational video. Those videos can be seen in the tradition of example-based learning and modeling. Example-based learning has been shown to be a powerful instructional method in early skill acquisition. Examples demonstrate a problem solution to students, either by providing them with a written, worked-out problem solution to study (i.e., worked examples; see, Atkinson, Derry, Renkl, & Wortham, 2000 ; Sweller, Van Merriënboer, & Paas, 1998) or by allowing them to observe an expert performing the task live or on video (i.e., modeling examples; Bandura, 1977 ; Collins, Brown, & Newman, 1989). For cognitive tasks, modeling examples require the model to verbalize his/her cognitive actions while performing the task (e.g., Wouters, Paas, &

Merriënboer, 2008).

For cognitive tasks that require the processing of complex visual information, it is crucial that the student not only hears the expert's verbal explanations, but can also see the material the expert is looking at. However, this may not suffice. As Bandura (1977) noted, to learn from modeling examples students have to attend to the important features of the modeled behavior. The verbal explanations of the expert can only guide the students' attention to the important features of the material when students know exactly what the expert is referring to. However, the chance that they simultaneously attend to the same features is very small, as was shown by the eye tracking research described above. Thus, when learning from modeling examples that involve complex visual material, novices might need attention guidance to those task aspects that the expert is attending to. Otherwise, especially on dynamic tasks, they may miss important information relevant for understanding and learning from the example.

Although several studies exist on attention guidance via cueing instructional material (for a review: Koning, Tabbers, Rikers, & Paas, 2009), the decision concerning which information will be highlighted and when often remains arbitrary. In particular, since research has shown that experts cannot estimate the knowledge level of novices appropriately (Hinds, 1999). Thus, it is very unlikely that they would be able to estimate appropriately, where to place a cue for a novice. On the other hand, research has shown that choosing a cue based on eye movements of successful problem solvers, enhances the probability for correctly solving an insight problem (Grant & Spivey, 2003). The question remains, however, whether attention guidance based on eye movements, not only as a single cue but the entire perceptual process of the expert, cannot just influence insight problem performance on the task at hand, but also enhance learning. Learning refers to the resilient change in a person's knowledge about a task that enables him or her to independently perform that task after practice (Simon, 1983).

In an earlier study, we could show that students' attention can be guided directly by the eye movements of an expert and that this influences learning (Jarodzka et al., in preparation). We developed modeling examples for a classification task in which an expert's eye movements and verbal explanations were recorded while he was performing this task. Participants who studied examples in which the expert's eye movements were displayed either as a dot on the fixated area or by blurring non-fixated areas (spotlight display), closely followed the expert's gazes during example study. The spotlight display led to significant improvements in learning in terms of visual search during the test, and the dot display led to enhanced classification performance on the test. These findings showed that guiding students' attention can go beyond guiding thought, to guiding learning.

Still, two open questions remain. First, since none of the displays was optimal, the current study aimed at improving both types of display. The dot display partially occluded rel-

evant problem features. Thus, instead of a solid dot, the expert's gazes are displayed as a circle. For the spotlight display, we decided to use a less intrusive blurring so that a holistic impression of the overall scene can be gained. This was done by compressing the video on non-attended areas. This procedure has shown to be well accepted by viewers (Nyström & Holmqvist, 2007). Second, although the classification task in the study described above was visually rich, the task in itself was simple. For this reason the benefit of this instructional approach might not have fully unfolded, because the task itself was too easy. Thus, the current study uses a medical diagnosis task based on video cases, which is not only a visually rich task, but is also composed of a complex underlying decision tree.

### Research Question - Hypothesis

In line with prior research, we hypothesize that attention-guidance based on expert's eye movements will foster learning of perceptual skills not only in a simple classification task, but also in medical diagnosis. Since both ways of display were improved, we assume learning to enhance in terms of a better diagnostic performance.

## Method

### Participants and Design

Participants were 60 medical students in their final year of the University of Aarhus (age: $M$ = 26.57 years, $SD$ = 2.03; 41 female), who had no prior knowledge on the task and had normal or corrected-to normal vision. They had been randomly assigned to one of three conditions ($n$ = 20 each): (1) control condition with no attentional guidance, (2) attentional guidance by a circle on fixated areas based on the model's eye movements (circle display), (3) attentional guidance by blurring non-attended areas and leaving fixated areas sharply displayed (spotlight display).

### Apparatus and Materials

**Eye tracking equipment**  The expert model's eye movements were recorded with a SMI High Speed eye tracking system with a temporal resolution of 240 Hz and the iView X 2.2 software. These eye tracking data were edited with BeGaze 2.3 software (www.smivision.com) and self-programmed MatLab algorithms. All video material was presented to the participants via Experiment Center 2.2. The questionnaire in the testing was presented via e-prime 2.0 software.

**Modeling examples**  The modeling examples for the control group consisted of four digital videos (.avi format), sized 720 × 576 pixels and presented in fullscreen on a 1280 × 1024 pixels resolution (corresponding to 17.07 × 13.65 inches). Each video depicted a single infant (between 4 hours and 8 months old), whereby two infants deployed behavioral patterns corresponding to a focal seizure and two infants deployed different types of normal behavior (benign sleep myoclonus, infantile masturbation). The original sound was removed from the videos, because parents and clinical staff were talking, which would disturb the use of verbal explanations. The duration of the videos was between 71 and 103 seconds. All videos included a spoken description and diagnosis of the behavior by the expert model. The expert was a physician of pediatric neurology, with extensive experience in diagnosing epileptic seizures. Rather than using the expert's natural performance of these tasks as an example we decided to instruct the expert to behave didactically, that is, to explain to novice students what the relevant aspects of the behavioral pattern shown in each video are. Each recording was replayed to the expert so that he could self-evaluate the replay data based on a number of statements (e.g., for a novice student, the disease is explained in enough detail, in comprehensible terms, et cetera; cf. Jucks, Schulte-Löbbert, & Bromme, 2007), and if necessary, he could re-record it. This was done, because a prior study had shown that experts use knowledge-based shortcuts in verbal and eye tracking data due to automated processes as well as using many technical terms that a novice student would not understand (shortcuts in this domain, cf. Balslev et al., in preparation).

In the circle display condition, participants received the same examples as the control group but those additionally included the expert's eye movements. These were created using the manufacturer rendered "fixation scanpath display function". The saccadic definition was set at a peak velocity threshold of 40/s. The fixations were displayed as yellow circles with a line thickness of one pixel and a gaze trail for a temporal window of 1 sec. In the spotlight display condition, potentially distracting features in the unattended areas were filtered out. That is, the focus of the expert's attention (with a radius of 32 pixels) was visible as usual, whereas the areas surrounding it were blurred' by off-line foveation via video compression on non-attended areas (Nyström & Holmqvist, 2007). Figure 1 shows a screen shot from each of the three conditions.

**Tests**  Participants were shown six new realistic videos for a mean duration of 31.00 seconds ($SD$ = 18.35) of different children displaying different types of behavior (3 × seizures and 3 × normal behavior). The duration of the testing video depended on the duration of the seizure / normal behavior. Afterwards, their diagnositc performance was assessed by answering multiple-choice questions on those videos: (1) indicating from a list of body parts, which was moving, (2) indicating from a list the type of the movement, (3) indicating, whether the face was involved and whether or not this was important for the diagnosis, (4) indicating the level of consciousness of the child, (5) indicating, whether awaking the child would change the movement, if child was asleep, and (6) indicating, whether touching the child changes the movement.

### Procedure

The recording ran in individual sessions of approximately 45 minutes each. At the beginning, participants filled in a ques-

Table 1: Screenshots from the three conditions used in the study.

| Control | Dot display | Spotlight display |
| --- | --- | --- |
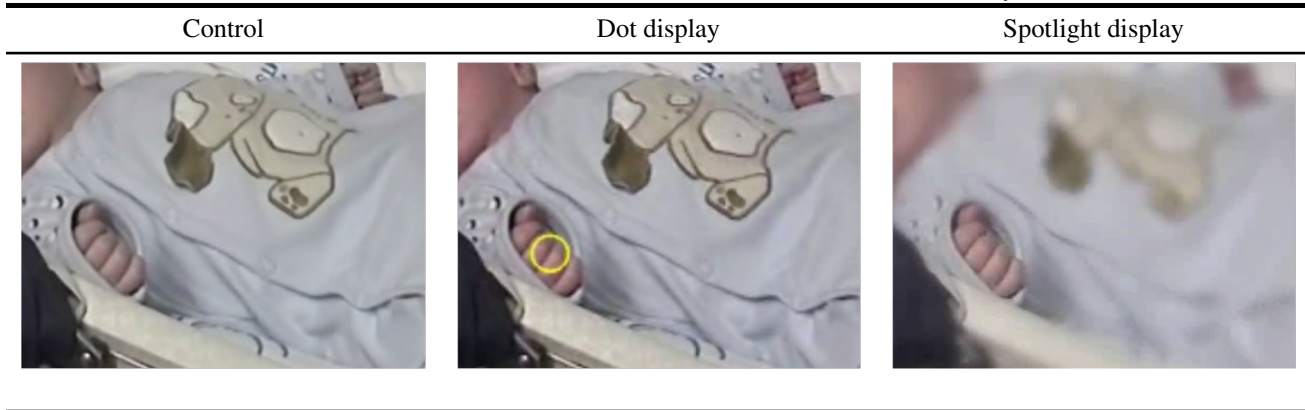


tionnaire on their prior knowledge in this task and their demographic data. Then, they received a short introduction to the topic, stating very general information on seizures and the importance to distinguish them from normal behavior. Then, the learning phase started. Participants were told that they will subsequently receive videos of the to-be-learned disease, where an expert explains the according movements and behavioral pattern. Depending on the condition, they were told that they will additionally see where the expert's attention was attracted to on the video. Before watching the learning videos, participants received the age, gender, and a short problem description of the patient.

In the testing phase the testing videos were replayed once. Afterwards, each video disappeared, resulting in a blank screen. Then, the participants had to answer the multiple-choice questions in an arbitrary order. This procedure was repeated for six new patient video cases.

### Data Analysis

**Test performance**   The construction and scoring of the performance measure was derived from a task analysis and by the help of domain experts. Accordingly, to diagnose a focal seizure, the following guidelines should be applied: (1) correctly stating which part of the body is involved in the movement, (2) correctly stating how this part moves, (3) correctly stating, whether the face was involved and whether or not this is important for the diagnosis, (4) correctly indicating the child's level of consciousness, (5) correctly indicating, whether awaking the child would change the movement, if child was asleep, and (6) correctly indicating, whether touching the child would change the movements. Hence, participants could receive a maximum of six points per video (1 point for each category).

### Results

For all statistical tests reported here, a significance level of .05 is used. Means and standard deviations for each condition are given in Table 2.

Table 2: Means (and SD) for Testing Performance for Diagnosing Seizures and Differential Diagnoses.

| | | Control group | Circle display group | Spotlight display group |
| --- | --- | --- | --- | --- |
| Testing | Seizure diagnosis | 3.25 (0.47) | 3.38 (0.41) | 3.90 (0.62) |
| | Differential diagnosis | 3.78 (0.59) | 3.48 (0.81) | 3.57 (0.69) |

### Seizure Diagnosis

An ANOVA showed significant differences between conditions in performance on the multiple choice test, $F(1, 59) = 9.13$, $p < .01$, $\eta_p 2 = .24$. Bonferroni post-hoc tests indicated that the spotlight display condition outperformed the circle display condition ($p < .01$) and the control condition ($p < .01$), while the control condition and the circle condition did not differ significantly.

### Differential Diagnosis

An ANOVA showed no significant differences between conditions, $F < 1$.

## Discussion

This experiment showed that attention guidance based on displaying expert's eye movements in video-based modeling examples fostered learning in terms of improved diagnostic skills. Participants in the spotlight display group outperformed the control and the circle display group in diagnosing epileptic seizures. No differences were found in diagnosing normal behavior.

These findings leave us with two questions: (1) Why did both types of eye movement displays resulted in such differential effects and (2) why does this effect occur for diagnosing seizures, but not for diagnosing the differential diagnosis?

Considering the first question, the fact that the circle display did not enhance learning is surprising. Although, one study found a negative effect on learning by displaying the model's eye movements based on the manufacturers' gaze replay functions (Van Gog et al., 2009), three others found a positive effect of a comparable visualization (Chen et al., 2009 ; Litchfield et al., 2008 ; Jarodzka et al., in preparation). However, only the latter three studies used visually rich learning tasks. Adding information to a display in terms of eye movements, might only be a benefit for visually rich tasks. In this study, a visually rich task was also used, but what differed was the fact that the display was not a solid dot, as for the remaining three studies, but a fully translucent circle. Might it be that the total translucence in terms of a circle reversed the positive learning effect? This might be tested in future studies by investigating the students' ability or willingness to follow the circle during learning. Another possibility is that the circle display increased mental effort due to a noisy type of display? Van Gog et al. (2009) found a higher mental effort in their study for this display, which lead to detrimental effects on learning. This should be investigated in future research by assessing mental effort in the learning and the testing phase. In contrast, the spotlight display, which was rather an unintrusive guidance, might have enabled the students to infer the element behind the cue and thus, lead to a holistic impression of the behavioral pattern.

The second question, about the different effects for seizure and differential diagnosis, has two competing answers. First, it might be that detecting the symptoms of a seizure, strongly relies on interpreting the perceptual input. Whereas detecting the symptoms of types of normal behavior requires more conceptual knowledge. This type of knowledge, however, was not varied between the groups in the current study. Second, it might be that the lack of an effect for the differential diagnosis is due to the type of material used in this study. One type of normal behavior (benign sleep myoclonus) was quite easy to detect, because both children in training and in testing were asleep. Neither of the others was asleep. Thus, this cases might have been too easy. The other normal behavior (infantile masturbation) was trained with an older child, whereas the testing occurred with younger children. Thus, thus testing might have been too difficult. Both possible reasons should be investigated in future research with more cases.

In sum, the current study provided an interesting, first approach to train perceptual skills in medical diagnosis. Still many research questions remain. Not only the above mentioned issues should be further investigated, but also additional improvements of the training are conceivable. We trained the students in this case only for a short time and only within individual learning. Training students in longer sessions that allow them to re-view the cases and discuss them with peers might further improve the training. On the other hand, the training effects should be also investigated in a more direct manner via detailed analyses of potential influences on participants' eye movements.

## Références

Antes, J. R., & Kristjanson, A. F. (1991). Discriminating artists from nonartists b their eye-fixation patterns. *Perceptual and Motor Skills*, *73*, 893-894.

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. (2000). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research*, *70*, 181-214.

Balslev, T., Jarodzka, H., Holmqvist, K., Grave, W. S. de, Muijtjens, A., Eika, B., et al. (in preparation). How do paediatricians do it? the influence of experience and training on attention and clinical reasoning.

Bandura, A. (1977). *Social learning theory.* Englewood Cliffs, NJ : Prentice-Hall.

Boshuizen, H., & Schmidt, H. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates, and novices. *Cognitive Science*, *16*, 153-184.

Canham, M., & Hegarty, M. (2010). Effects of knowledge and display design on comprehension of complex graphics. *Learning and Instruction*, *20*, 155-166.

Charness, N., Reingold, E. M., Pomplun, M., & Stampe, D. (2001). The perceptual aspect of skilled performance in chess: Evidence from eye movements. *Memory and Cognition*, *29*, 1146-1152.

Chen, Y., Gale, A. G., & Evans, A. (2009). The feasibility of vision-supported computer-based training in digital mammography. *Breast Cancer Research*, *11*, 10.

Collins, A. F., Brown, J. S., & Newman, S. (1989). Cognition and instruction: Issues and agendas. In L. Resnick (Ed.), (chap. Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics.). Mahwah, NJ : Erlbaum.

Egger, J., Grossmann, G., & Auchterlonie, I. A. (2003). Benign sleep myoclonus in infancy mistaken for epilepsy. *British Medical Journal*, *326*, 975-976.

Feltovich, P. J., & Barrows, H. S. (1984). Issues of generality in medical problem solving. In H. G. Schmidt & M. L. D. Volder (Eds.), *Tutorials in problem-based learning. new directions in training for the health professions.* (p. 128-142). Assen/Maastricht : Van Gorcum.

Grant, E. R., & Spivey, M. J. (2003). Eye movements and problem solving. guiding attention guides thought. *Psychological Science*, *14*.

Hansen, J. K., & Balslev, T. (2009). Hand activities in infantile masturbation: A video analysis of 13 cases. *European Journal of Paediatric Neurology*, *13*, 508-510.

Helleberg, J. R., & Wickens, C. D. (2003). Effects of data-link modality and display redundancy on pilot performance: An attentional perspective. *The International Journal of Aviation Psychology*, *13*, 189-210.

Hinds, P. I. (1999). The curse of expertise: The effects of expertise and debiasing methods on predictions of novice performance. *Journal of Experimental Psychology: Applied*, *5*, 205-221.

International classification of mental and behavioural disor-

ders (icd-10) [Manuel de logiciel]. (2006). Genf : World Health Organisation (WHO).

Jarodzka, H., Gog, T. van, Dorr, M., Scheiter, K., & Gerjets, P. (in preparation). Guiding attentions guides thought, but what about learning? eye movements in modeling examples. *NN*.

Jarodzka, H., Scheiter, K., Gerjets, P., & Van Gog, T. (2010). In the eyes of the beholder: How experts and novices interpret dynamic stimuli. *Journal of Learning and Instruction*, *20*, 146-154.

Jucks, R., Schulte-Löbbert, P., & Bromme, R. (2007). Supporting experts' written knowledge communication through reflective prompts on the use of specialist concepts. *Journal of Psychology*, *215*, 237-247.

Koning, B. B. D., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educational Psychology Review*, *21*, 113-140.

Krupinski, E. A. (2005). Visual search of mammographic images: Influence of lesion subtlety1. *Academic Radiology*, *12*(8), 965 - 969.

Krupinski, E. A., Tillack, A. A., Richter, L., Henderson, J. T., Bhattacharyya, A. K., Scott, K. M., et al. (2006). Eye-movement study and human performance using telepathology virtual slides. implications for medical education and differences with experience. *Human Pathology*, *37*(12), 1543 - 1556.

Kuipers, B., & Kassirer, J. P. (1984). Causal reasoning in medicine: Analysis of a protocol. *Cognitive Science*, *8*, 363-385.

Kundel, H., Nodine, C., Krupinski, E., & Mello-Thoms, C. (2008). Using gaze-tracking data and mixture distribution analysis to support a holisitc model fort he detection of cancers on mammograms. *Academic Radiology*, *15*, 881-886.

Lesgold, A., Rubinson, H., Feltovich, P., Glaser, R., Klopfer, D., & Wang, Y. (1988). The nature of expertise. In M. T. H. Chi, R. Glaser, & M. Farr (Eds.), (p. 311-342). Hillsdale, NJ : Erlbaum.

Litchfield, D., Ball, L. J., Donovan, T., Manning, D. J., & Crawford, T. (2008). Learning from others: Effects of viewing another person's eye movements while searching for chest nodules. In B. Sahiner & D. J. Manning (Eds.), *Proceedings of spie medical imaging 2008: Image perception, observer performance, and technology assessment* (Vol. 9). San Diego, CA, USA : SPIE.

Manning, D. J., Gale, A., & Krupinski, E. A. (2005). Perception research in medical imaging. *The British Journal of Radiology*, *78*, 683-685.

Nodine, C. F., Kundel, H. L., Lauver, S. C., & Toto, L. C. (1996). Nature of expertise in searching mammograms for breast masses. *Academic Radiology*, *3*(12), 1000 - 1006.

Nyström, M., & Holmqvist, K. (2007). Deriving and evaluating eye-tracking controlled volumes of interest for variable-resolution video compression. *Journal of Electronic Imaging*, *16*(1).

Patel, V. L., Evans, D. A., & Groen, G. J. (1989a). Biomedical knowledge and medical reasoning. In D. A. Evans & V. L. Patel (Eds.), *Cognitive science in medicine: Biomedical modeling* (p. 53-112). Cambridge, MA : The MIT Press.

Patel, V. L., Evans, D. A., & Groen, G. J. (1989b). Reconciling basic science and clinical reasoning. *Teaching and Learning in Medicine*, *1*, 116-121.

Patel, V. L., & Kaufman, D. R. (1995). Clinical reasoning and biomedical knowledge: Implications for teaching. In J. Higss & M. Jones (Eds.), *Clinical reasoning in the health professions* (p. 117-128). Oxford, UK : Butterworth Heinemann.

Pozzi, S., Noss, R., & Hoyles, C. (1998). Tool in practice, mathematics in use. *Educational Studies in Mathematics*, *36*, 105-122.

Schmidt, H. G., & Boshuizen, H. P. A. (1992). Encapsulation of biomedical knowledge. In D. A. Evans & V. L. Patel (Eds.), *Advanced models of cognition for medical training and practice* (p. 265-282). New York, NY : Springer Verlag.

Schmidt, H. G., & Boshuizen, H. P. A. (1993). On acquiring expertise in medicine. *Educational Psychology Review*, *5*, 205-221.

Simon, H. A. (1983). Why should machines learn? In R. S. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (p. 25-38). Palo Alto, CA : Tioga.

Sweller, J., Van Merriënboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychological Review*, *10*, 251-296.

Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual attention while driving: Sequences of eye fixations made by experienced and novice drivers. *Ergonomics*, *46*.

Van Gog, T., Jarodzka, H., Scheiter, K., Gerjets, P., & Paas, F. (2009). Attention guidance during example study via the model's eye movements. *Computers in Human Behavior*, *25*, 785-791.

Van Gog, T., Paas, F., & Van Merriënboer, J. J. G. (2005). Uncovering expertise-related differences in troubleshooting performance. combining eye movement and concurrent verbal protocol data. *Applied Cognitive Psychology*, *19*, 205-221.

Vogt, S., & Magnussen, S. (2007). Expertise in pictorial perception: Eye movement patterns and visual memory in artists and laymen. *Perception*, *36*, 91-100.

Whitehead, A. N. (1929). *The aims of education.* New York, NY : MacMillan.

Wouters, P., Paas, F., & Merriënboer, J. J. G. V. (2008). How to optimize learning from animated models: A review of guidelines based on cognitive load. *Review of Educational Research*, *78*, 645-675.