 JrnlID 11412_ArtID 9153_Proof# 1 - 18/07/2012

Computer Supported Learning
DOI 10.1007/s11412-012-9153-0

Interactive visual tools as triggers of collaborative reasoning in entry-level pathology

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Received: 7 March 2012 / Accepted: 12 July 2012

Abstract The growing importance of medical imaging in everyday diagnostic practices poses challenges for medical education. While the emergence of novel imaging technologies offers new opportunities, many pedagogical questions remain. In the present study, we explore the use of a new tool, a virtual microscope, for the instruction and the collaborative learning of pathology. Fifteen pairs of medical students were asked to solve diagnostic tasks in a virtual microscopy learning environment. The students' collaborative efforts were analysed on the basis of approximately 20 hours of video recordings. Our analyses show how students use the technology as a mediating tool to organize, manipulate and construct a shared visual field, and later, shared understanding of the problem and solutions. Organization of the visual field is done through multimodal referential practices: gestures, three dimensional manipulation of the image and paced inspection of the specimen. Furthermore, we analyse and describe how the aforementioned practices coincide with students' medical reasoning in this particular learning context. The analysis of medical students' diagnostic work illustrates the collaborative potential of the virtual microscopy environment and how such interactive tools render the traditional distinction between collaborating around or

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through computers irrelevant, as even face to face collaboration becomes enacted through technology. Finally, we argue that as technologies develop, understanding the technical side of image production, or any representation, becomes an integral part of the interpretative process. How this knowledge is communicated to the students may play a substantive role in how students learn to interpret medical images.

Keywords Medical education · Collaboration · Virtual microscopy · Referential practices

Introduction

The growing importance, omnipresence and diversity of medical imaging in everyday diagnostic practices (see e.g., Krupinski 2010) pose challenges for practitioners of medicine, medical educators, and medical students. For medical education, the emergence of novel imaging technologies offers new opportunities for using high fidelity illustrations. However, many pressing pedagogical questions remain in the wake of this development. In the present study, we explore the use of a new tool, a virtual microscope, for the instruction and the collaborative learning of introductory pathology.

Traditionally, research on the development of visual diagnostic skills in medicine has mostly concentrated on the differences between novice and expert performance. Performance differences have been studied in relation to cognitive and perceptual processes, as well as the individual characteristics of the diagnostician (Norman et al., 1992; Krupinski 2010). Although highly informative, this kind of research does not necessarily or directly address many of the everyday educational questions related to medical imaging. For example, pathology, i.e., the study of the cause, development, and (both morphological and clinical) consequences of diseases (Robbins 2010), is highly relevant knowledge to doctors of any speciality. Pathology is studied to acquire a better understanding of the human body, its conditions and how these are affected by the possible treatments. Yet, only a few medical students become professional pathologists; the majority will not need to examine pathological samples in their everyday work. Thus, educational problems remain different from the problems of professional development of specialists.

Due to the nature of medicine as a discipline and practice, much time and effort have been devoted to developing fool proof diagnostic systems and heuristics that could reduce the number of errors or possible diagnostic interpretations to a minimum. However, overemphasis on improvement in diagnostic performance from the early stages of instruction appears to be ill guided, or at least, the limitations of such ambitions should be acknowledged. Learning environments in which the opportunity to make errors is minimised do not necessarily lead to better performance in the long term (Eva 2009; Pathak et al. 2011, see also Lesgold et al. 1988; Myles-Worsley et al. 1988; Patel et al. 2005). Similar caution should be applied in the evaluation of new technological learning environments. Treating technological and pedagogical innovations such as virtual learning environments as 'either-or' (either they improve performance or they do not) may be reasonable in many professional settings but not from an educational point of view. In the field of CSCL, the realisation that 'media effectiveness is a myth' (Dillenbourg et al. 2009, p. 6; see also Cook 2009; Säljö 2010) has occurred simultaneously with the realisation that enhancing learning with the help of technology both requires and, in some cases, induces a process of co-evolution of existing practices and of new technology. On one hand, technological tools shape the way users reason and engage in a task, as well as affecting future learning and clinical practices

(Schoultz et al. 2001; Ritella and Hakkarainen 2012; Kushniruk et al. 1996; Kuutti and Kaptelinin 1997; Bransford and Schwartz 1999; Säljö 2010). On the other hand, a new tool is not used in a vacuum but in an intellectual and institutional landscape which, although capable of evolving, affects how such a new tool, technology or practice is adopted and adapted (Overdijk et al. 2012; Arnseth and Ludvigsen 2006; Crook and Light 2002). Therefore, examining the actual practices and reasoning that unfold within the (computer-supported) learning context is necessary in order to successfully implement a new technology in medical education (Arnseth and Ludvigsen 2006; Säljö 2001). Methodologically, this Q4 means that the analysis should include attention to mental processes, as well as to the activity system and social interaction of the learning situation (Lehtinen 2012). Q5

The present study focuses on the interaction between individuals and how this interaction is mediated by language, referential practices and technology, which also constitute the unit of analysis (Säljö 2009; Wertsch 1998). As summarized by Roschelle, "[o]nly when the actions are considered in relation to the situation is sufficient information available to construct intelligible interpretations of what is taking place" (1992, p. 238). Thus, in order to understand these situated actions in their proper context, we analyse them in relation to the task at hand: medical reasoning in microscopic pathology. The analysis of how the students—despite their limited knowledge in pathology—are able to perform diagnostic reasoning by means of the learning environment is interesting both in substantive terms, i.e., in terms of learning, and in terms of understanding how the tool contributes to the development of productive forms of collaborative learning. With respect to novices' relative lack of domain knowledge and use of visualization technologies our study concurs with the foundational work in the field of CSCL by Roschelle (1992). He studied a student dyad working with a screen-based computer simulation of Newtonian physics, arguing that "convergent conceptual change is achieved incrementally, interactively, and socially through collaborative participation in joint activity" (p. 239). Conceptual convergence is achieved by construction of "deep-featured" situation and interplay of theory-constitutive metaphors, through iterative cycles of turn-taking, which, in turn, rely on progressively higher standards of evidence for convergence (Roschelle 1992). By imposing talk and gestures and the symbols on the screen they were able to make sense of the scientific object although they did not master the knowledge domain. The shared screen was thus necessary for making sense of the phenomena by the simultaneous use of deictic expressions and visual conduct. As pointed out in a re-analysis of Roschelle's study by Koschmann and Zemel (2009) visual means enable students to participate in a process of discovery in which they are able to talk about something that they yet do not know what it is (see also Rystedt et al. 2011).

The interaction between converging scientific knowledge and employing various forms of referential practices has been analysed in-depth by e.g., Roth (2000) and Q6 Hindmarsh and Heath (2000). Deictic and iconic gestures are used to select, describe and explain scientific phenomena, especially if the students do not yet have a firm command of appropriate scientific language. Hindmarsh and Heath (2000) demonstrated how mutual orientation is achieved by dynamic co-ordination of visual conduct and how these referential practices are embedded in the context in which they are acted out. This strand of research is especially interesting in the context of virtual microscopy and pathology, as the whole domain relies on, and requires, making sense of visual information. Rendering pathological phenomena visible also involves practices for producing and manipulating visual representations. How samples are collected and processed (e.g., different stainings) affect the formation of morphological artifacts well as which morphological features are pronounced and in which manner. Thus, the production of the samples adds another layer of complexity to the interpretation of visual information. In contrast to studies by Roth and Roschelle, which deal with simplified representations of scientific phenomena, our study extends the analysis into a domain in which the visual representations are; firstly, abundant with diagnostically irrelevant information, secondly, students have to realize that even normal (i.e., healthy) cellular anatomy contains considerable variation between individuals, and, thirdly, biomedical phenomena often cannot be understood by means of reduction into a simple normal-abnormal dichotomy, but require judgement on this continuum. This presents an additional challenge for the students: how to collaboratively choose which features to examine and discuss becomes even more important. A concomitant phenomenon has previously been studied by Alac (2008). Her studies reported on neuroscientists' work with brain scans in fMRI laboratories. While virtual slides of pathology are, in principle, pictures of tissue samples, fMRI images are numerical data that are computationally converted to visual representations. Thus, whereas artifacts in pathological samples are mostly of mechanical nature, i.e., products of the sample collection methods, fMRIs are images of what "visual representations of what is not visual" and the artifacts that are present are not present in the original source (Alac 2008, p. 483). However, our argument converges with hers in that according to our analysis, the virtual microscope becomes a spatially and temporally controlled site of interaction, "a process situated at the intersection between instruments and technology, practices, settings, and the practitioners' embodied accounts" (Alac 2008, p. 503). Our interest lies in how and to what extent medical students are able to achieve this.

Furthermore, our analytical point of view builds on the idea that the collaborative emergence of novel knowledge practices is captured in breakdowns and discontinuities of activity, which "push the participants personally or collectively to explore novel possibilities—and utilize resulting changes in the situation in order to find opportunities to move inquiry forward" (Ritella and Hakkarainen 2012, p. 15; see also Engeström 1987; Wertsch 1998). Developing ways to cope with situations one cannot solve by simply relying on already existing skills, and realising how to extend the domain knowledge of the participating individuals, are at the heart of collaborative learning. Implementing a new tool such as a virtual microscope into educational practices introduces a discontinuity at least on two levels. First, new affordances of technology alter, and are adapted to, institutional practices, such as pedagogical organisation of e.g., medical education. Second, as the users adapt and the technology is adopted, existing practices will evolve and be transformed. To inform further pedagogical development, the current study explores how an institutional decision (introducing virtual microscopy as means of collaborative self-study for students) is realized in practice.

WebMicrosope—a virtual microscopy environment

In this study, we use a computer application as a tool aimed at triggering and facilitating collaboration around a computer. WebMicroscope (for a demo, see http://www.webmicroscope.net/) is a Web-based virtual microscopy application used to view tissue samples that are digitised at a very high resolution, and thus allowing the users to move around and zoom in on any part of the specimen (up to 40 times magnification) (Helin et al. 2005). In addition to general controls (zoom, contrast and brightness), slides can be enhanced with visual and textual cues (note: textual cues were not used in the present study), i.e., annotations, which appear as links on the right side of the user interface (see Fig. 1). Each annotation link leads to a view (area and zooming level) that has been specified by an experienced pathologist, and it may contain further visual cues, such as arrows or circles (see Figs. 2 and 4). Rather than giving direct prompts on what to do and how to do it, annotations are used as 'conversation pieces', which guide the students to discuss the relevant features of the specimen.

Collaboration is interesting in terms of professional development, as the meaning of medical images has to be communicated and negotiated among doctors of different sub-specialties, but it is also of pedagogical interest. WebMicroscope makes the specimen easily accessible, as it presents it on a computer screen where it can be simultaneously examined, pointed at and discussed by students without the need for constant turn-taking on an eyepiece as is the case with a traditional light-microscope. The collaborative examination of the specimen is not limited to the areas predetermined by each participant (on which collaborators are then invited to comment) but spans across the whole interpretative process from the search to the selection of clinically relevant areas and, finally, to the diagnostic decision.

Research questions

Following the more or less explicit recommendations of previous research (e.g., Arnseth and Ludvigsen 2006; Säljö 2009), we aim to analyse the strategies students employ and the interactions they engage in. Thus, our research questions are as follows:

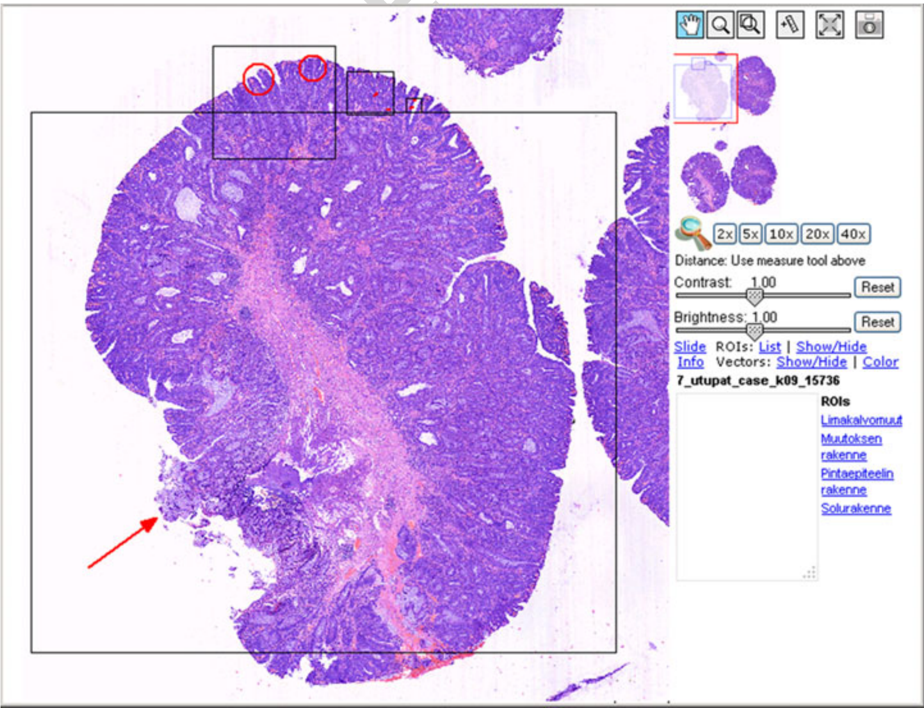


Fig. 1 Webmicroscope user interface

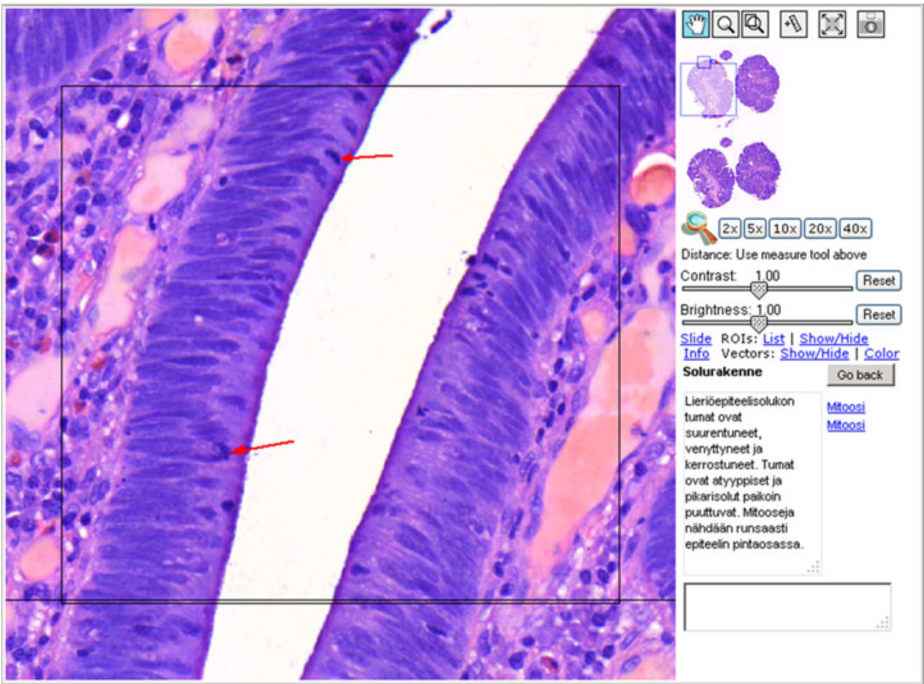
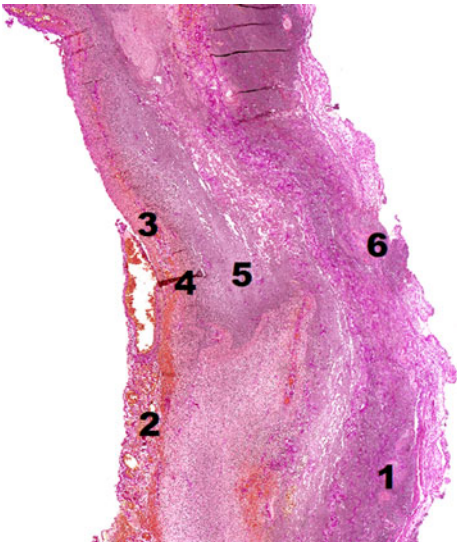


Fig. 2 Virtual slide with visual and textual cues

1) What activities are triggered by the computer-based learning environment that makes use of virtual tissue samples?
2) What referential practices do students employ to organize their collaborative diagnostic reasoning as well as how it is contingent on and supported by the virtual microscopy environment?

Fig. 3 Gallbladder; numbers point to inspected areas



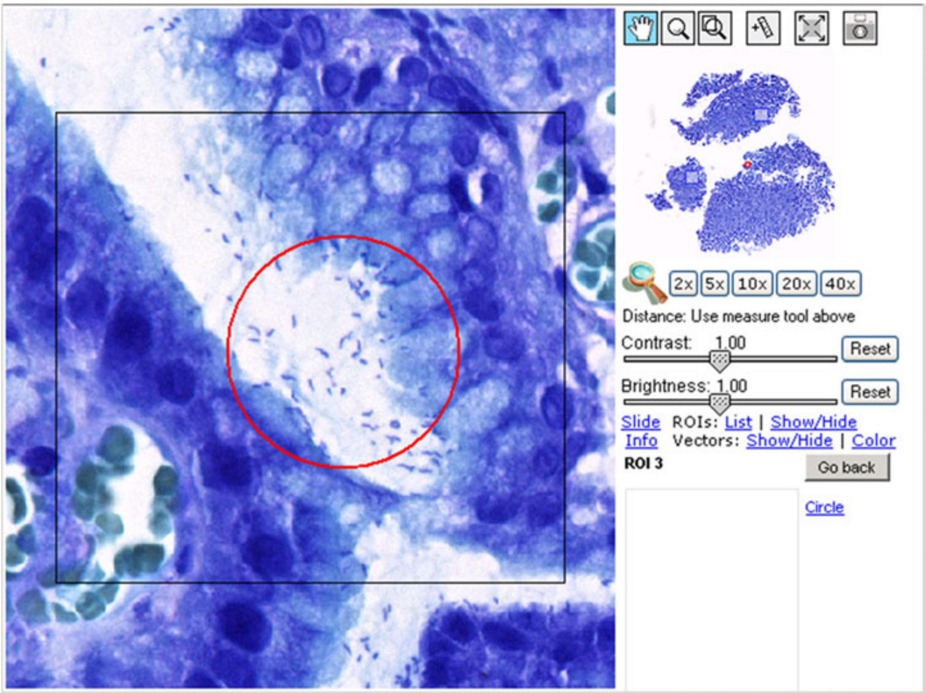


Fig. 4 Annotated helico bacterium

3) What kind of strategies do the students mobilize in cases of uncertainty?

Method

Participants and context

The 30 participants (15 pairs) were second-year medical students attending an introductory course in pathology. The course is a mandatory requirement to enter the clinical phase. Participation in the study was voluntary, and the students were allowed to form pairs by themselves. WebMicroscope was implemented in the course partly as a self-study material bank and partly as a tool for demonstration during instruction.

Materials and procedure

The analysis is based on approximately 20 hours of video recording of pairs of students solving four diagnostic tasks twice: at the beginning and at the end of the course. Two of the tasks were without any annotations, whereas two had 4 to 6 visual cues. The pairs were instructed to speak aloud as much as possible. Furthermore, the students provided their answers using a pre-structured form, in which they were required to write both findings and diagnosis for each case. The interactions of the students were videotaped from two angles: from behind (capturing the computer screen and the students' gestures) and from the students' left side (capturing their actions and facial expressions).

Analysis

The video analysis was performed collaboratively by researchers at the University of Turku, Finland, and the University of Gothenburg, Sweden, (one of the recruited pairs was Swedish speaking) in multiple iterative cycles. The analysis was conducted in ELAN, a multimedia analysis software tool developed at the Max Planck Institute for Psycholinguistics. ELAN allows synchronous viewing and annotating of multiple video files. Due to the visual and dynamic nature of our data, keeping the analysis as close as possible to the original data for as long as possible was deemed important. Thus, instead of analysing transcripts, episodes of interest were marked, analysed and themed in ELAN. After the initial, independent analysis, researchers from both universities compared and refined notes on the general description of the students' strategies. With our interest in learning and emerging practices (Ritella and Hakkarainen 2012), we then systematically looked for and marked episodes in which the students showed the most prominent signs of uncertainty, that is, for example, when they expressed explicitly that they do not know what they are looking at (e.g., Excerpt 2) or when they disagreed upon what they see (e.g., Excerpt 3 and 8). Discontinuity or uncertainty indeed triggered episodes in which the students engaged in the most observable, deliberate and interactive reasoning. Therefore, these episodes were both analytically interesting and methodologically accessible. The episodes were first given short written descriptions, which were discussed in group meetings, and then later organised into common themes based on the dominant strategies. Finally, we analysed the students' interactions with technology in each episode. Probably due to the naturalistic design of the study and relatively open learning environment, and assignment, a multitude of strategies emerged, of which the most salient are exemplified in the analysis. Transcriptions use the following notation: pauses are given in brackets (in seconds; a dot denotes a micro pause), and co-occurring talk is horizontally aligned and marked with square brackets. Actions are given in double brackets. Excerpts from the first (at the beginning of the course) and the second sessions (at the end of the course) are indicated after the excerpt number with ‘1st’ and ‘2nd’, respectively. However, as there seemed to be little if any change in students strategies between the two sessions, the excerpts presented here were chosen primarily on the basis of how well they exemplify the phenomena, and also on the basis of how coherent and concise they are as illustrations.

We will first exemplify the more general procedures (framing and identification), and how these are conducted through the employment of various forms of referential practices. Next, we move on to how students make sense of visual evidence through paced negotiation, and finally, how students deal with uncertainty by extending the frame reasoning. Of each episode we analyse the diagnostic reasoning and how it is enacted in the learning environment.

Results

At a general level, the students’ interpretative work oscillates between episodes of relatively unproblematic, smoothly flowing, diagnostic reasoning, and, on the other hand, more or less obvious tensions and discontinuities that are triggered by what the students see, remember and reason about. These periods of uncertainty and pondering are dealt with through a repertoire of strategies.

Framing the diagnostic process by identifying normal structures and abnormalities

Excerpt 1 exemplifies a prominent phase of the diagnostic process, namely *framing,* during which students establish a joint frame of reference for the subsequent diagnostic work. Pete and John inspect a specimen from a haemorrhagic, inflamed and necrotic gallbladder. They first note the origin of the specimen, as stated in the introductory information to each case. They then move on to examine the specimen and try to orient themselves by localising the main structures of the tissue:

Excerpt 1 (2nd)
100 Pete: Should we just start zooming then?
101 John: Yes where should we go?
102 (1.3)
103 Pete: Let's go there ((points at 1, Fig. 3.))
104 John: ((Zooms in to the area Pete pointed at.))
105 (0.8)
106 John: Gall bladder, wait, now what ((Zooms out.))
107 John: ((Points)) If it's gall bladder, is this then, inner surface
108 [or (1.0) this side…
109 [((Moves mouse cursor alternating between the different sides of
110 the tissue, 4–6, Fig. 3.))
111 (1.1)
112 John: ((Moves to the left side of the tissue and zooms in 2, Fig. 3.))
113 I guess this could be.
114 Pete: That's probably the inner surface. ((Zoomed on the outer
115 surface.))

During the *framing* phase, the students typically paid attention first to the given background information, i.e., age and gender of the patient as well as the origin of the pathological sample (lines 106–107), and then moved on to identify the major structures and dimensions of the specimen (107–115). While hand and mouse gestures are used for mutual orientation in the visual field, John also guides the level of the discussion by the oscillating between zooming levels. After zooming in to area Pete pointed at, John zooms out to denote his wish to discuss a structural level issue (106–108), i.e., which side is the inner surface of the gallbladder, thus inviting Pete to comment on it. Furthermore, the zooming level is used to limit the visual field to relevant areas of the specimen in order to tag or highlight the discussed features (112–115), allowing the effective use of deictic expressions ("this", "that") even without additional pointing (see also Excerpt 2). It should be noted that the identification of the inner and outer surfaces of the gallbladder proved to be problematic for many of the pairs, possibly due to the extremity of the medical condition at hand, which involved the complete eradication of one of the recognisable tissue layers (epithelium). It was evident across the data that the initial framing and subsequent search and interpretation were by no means trivial tasks, especially in cases consisting mainly of abnormal tissues, or in cases where students were uncertain of how the sample had been produced (see below for discussion on contextual knowledge).

Excerpts 2 and 3 demonstrate further how students use the zooming function and subsequent panning (movement around the specimen) to create and maintain a common visual point of reference. Furthermore, these excerpts embody a salient feature of the students' diagnostic process that follows the initial framing and orientation phase.

The rapid, collaborative and simultaneous inspection of areas is occasionally interrupted by either the identification of a pathological finding (204, 216) or by uncertainty (208–213). Visual information is classified either into normal features that can be ignored or into clinically relevant abnormalities that require further inspection and/or *identification*. Search and identification are guided by information obtained during the framing phase and monitored by both students.

After deciding which side of the tissue is the inner surface, John and Pete continue by moving around the specimen in order to identify diagnostically relevant features:

Excerpt 2 (2nd)

200 Pete: Blood, quite much at least.
201 (1.1)
202 John: Uhm.
203 (2.2)
204 Pete : Haemorrhage. ((Writes down.))
205 John: ((Moves up towards 3, Fig. 3.))
206 John: Yeah. ((Moves back towards a previously inspected area, 4,
207 Fig. 3.))
208 Pete: [(Lifts hand to point.) What?
209 John: [What?
210 John: ((Stops, zooms further in 4, Fig. 3.))
211 (4.5)
212 John: What could those be? (0.6) ((Zooms even further in 4, Fig. 3.))
213 Pete: I don't know.
214 (4.6)
215 John: ((Zooms out, moves right towards 5, Fig. 3.))
216 Pete: [Isn't this now at least some necrosis, or fibr…
217 John: [((Stop, zoom in, zoom out))
218 Pete: Because there is like [no…
219 John: [Well there are no cells.
220 [((Waves mouse cursor at 5, Fig. 3.))
221 Pete: Yeah.

In Excerpt 2, the somewhat smoothly flowing identification process is interrupted simultaneously by both Pete and John (208–209). From here on, their interaction unfolds embedded in the virtual microscope, that is, by zooming into (and thus highlighting) the appropriate areas (210, 212, 215, 217) as well as by occasional mouse gestures (220). As minimalist as this referential practice seems to an outsider, it does not prevent them from converging on the same tentative conclusion, which is confirmed by agreeing on the presence of necrosis on lines 218–221. Roschelle refers to such phenomena as being part of "progressively higher standards of evidence for convergence" (Roschelle 1992, p. 236), which enables participants to assess the level of their agreement. Later, John and Pete are not able to identify or ignore an abnormal tissue that they encounter and employ another strategy: comparison between the abnormal and the normal tissue. They decide to compare the specimen with a normal specimen from their online course materials (see Excerpt 5).

Before discussing how these uncertainties are dealt with, we will present how collaboration is further organized through paced negotiation of visual evidence and how students make sense of "external references" or visual cues.

Paced negotiation of visual evidence

In Excerpt 3, Liz and Joe are examining a kidney specimen, and they are about to start listing their findings. Liz claims to observe macrophages and is confident enough to make a note about it (301). However, this observation is questioned by Joe who asks her to indicate the location of the macrophages (304). Subsequently, Joe proposes an alternative with respect to the nature of the cells (307–308). This proposal leads to further exploration of the image, and finally, the conclusion is reached that the cells are not macrophages (310–328).

Excerpt 3 (2nd)

300 Joe: ((Moves around the specimen.))
301 Liz: [Macrophages, [I'll write it here. ((Begins to write.))
302 Joe: [((Stops.)) [Uhm.
303 (1.0)
304 Joe: Where do you see macrophages?
305 Liz: Well…
306 (1.5)
307 Joe: Are you absolutely sure if they are macrophages or just some
308 cancer cells? ((Waves mouse over salient cell locus.))
309 (1.6)
310 Liz: U::hm (.) Well, not right here… (0.6) …in this place, but…
311 (3.9)
312 Joe: ((Moves around the inspected area.))
313 Liz: Well, okay, they can be cancer cells.
314 Joe: ((Stops, hand off mouse.))
315 (0.7)
316 Liz: (Inaudible)
317 (1.6)
318 Joe: It may be a bit unsure to write macrophages there.
319 (0.8)
320 Liz: Well… ((laughs)) [but, but, we…
321 Joe: [If one is not absolutely sure there is. ((Laughs.))
322 Liz: … can we have a look at, can we have a look at some other place, 323 look at ((points))…
324 Joe: ((Moves to the area Liz pointed at and continues to move around 325 the specimen.))
326 (1.0)
327 Liz: Necrosis, yes. (2.4) No. (2.0) No. (0.8) (Inaudible.) (1.7) Okay, 328 well, it doesn't look like there is any there.

Excerpt 3 illustrates a typical sequence of collaborative work around the WebMicroscope: a rapid identification process interrupted by disagreement (or uncertainty) which triggers joint reasoning. The alternative views of the collaborating partners are explored further until some kind of agreement is reached. Agreements and disagreements between the students are communicated through verbal means, but also through the temporal regulation of the actions. Joe's continuous movement stops as soon as Liz suggests a finding that Joe disagrees with. While a mere suggestion can sometimes be ignored, the fact that Liz started to write down the contested finding prompted Joe to request a visual reference to the evidence (301–308). The pacing of the actions is further accentuated as Joe moves his hand off the mouse to explain his point of view (314). Liz asks to look elsewhere in the specimen and the movement resumes to its original pace (322). Again, pacing constitutes a form of referential practice to guide collaboration: While Joe moves around the specimen, Liz confirms the absence of macrophages verbally (324–328). The ease of executing this explorative task on a computer screen (compared with what would have been the case on a light microscope eyepiece) is noteworthy.

Making sense of visual cues

A visual cue can alert the students to examine and seek explanation for features they might have ignored earlier or dismissed as irrelevant. Thus, visual cues are, in essence, predetermined external references. In Excerpt 4, Lisa and Mary have already agreed upon the conclusion that the stomach tissue specimen they are inspecting contains a malign, cancerous abnormality. After inspecting the slide for approximately seven minutes (of a total of 10 minutes), they open an annotation, a visual cue, a link that leads to a certain area, zooming level and feature they have not commented on previously (see Fig. 4). Uncertain of what they see, they try to identify it and start seeking for an explanation.

Excerpt 4 (1st)

400 Lisa: I open the third one [here ready. ((Opens annotation, Fig. 4.))
401 Mary: [Yes.
402 (1.1)
403 Lisa: Ha ha, what are these?
404 (1.4)
405 Mary: A-ha.
406 Lisa: This is now probably… ((Zooms out.)) (6.0) From which part this
407 is, right from the edge. (2.1) Helico bacterium ((laughs)).
408 (0.9)
409 Mary: Yes.
410 Lisa: Looks like, no, or what can appear, bacteria are not visible in a 411 light microscope.
412 (0.6)
413 Mary: Ye:s. (1.5) Look at a slightly higher magnification.
414 Lisa: ((Zooms back in to the annotated area.))
415 (8.3)
416 Mary: What could it be then?
417 Lisa: ((Hand off mouse, both lean back.))
418 (8.3)
419 Lisa: Could it be some… (3.1) … some poison that causes stomach
420 cancer, some substance ((laughs)).
421 Mary: ((Laughs.)) I don't know at all.

Somewhat surprised by what they see (403, 405), and after a short orientation, Lisa comes up with the correct answer, i.e., helico bacterium (407), but dismisses it due to an incorrect assumption that bacteria are not visible in a light microscope (410–411; see also below for a discussion on the role of contextual knowledge). The discussion is co-regulated by zooming in (400, 414), zooming out (406) as well as by temporal/spatial gestures (417) and oscillates it between subcellular level (403, 416) and more general knowledge (406–407, 410–411, 419–420) in order to establish a causal link between different levels. Nevertheless, the clearly marked bacterium, although not noticed prior to opening the annotation, becomes salient and cannot be overlooked. Visual cues guide students to inspect areas that they would not have inspected on the basis of their own knowledge of organs and related diseases, thereby occasionally exposing them to unexpected visual information in need of clarification. For example, in Excerpt 4, Lisa and Mary were led to examine a feature they were not actively looking for, and they were surprised, even slightly confused, when they found it. This may explain a previous finding suggesting that visual cues can increase the number of false positives, i.e., an incorrect indication of assumed pathological features that are not present in the sample (Nivala et al. 2012). Faced with a clearly marked yet still unrecognisable pathological feature, the students might rely on over-explanation or even hypothesis-driven guesswork as in Excerpt 4. The analysis of this video material suggests that this is especially the case when the annotation or visual cue refers to normal tissue. Although the normality of some tissue(s) represents perfectly relevant diagnostic information in some cases (e.g., in deciding how far the disease has spread), the students seem to assume that visual cues, by definition, relate to a pathological abnormality rather than to normal tissue.

Dealing with uncertainty by extending the frame of reasoning

We now turn our analysis to how students deal with uncertainty and what strategies they are capable of employing in order to solve the problem at hand. We have given these strategies a common moniker of “extending the frame of reasoning”, as they all involve “taking a step back” from the current level of reasoning (cell, tissue, organ, patient level) in order to move forward. While the initial framing aims at pinning down incrementally specific facts about the specimen (or a part of it), extending the frame of reasoning is a reverse process. Tentative facts are produced from a larger medical context, and already secured or contested facts are evaluated in relation to differing levels of diagnostic and medical knowledge.

Although Excerpt 5 (almost direct continuation to Excerpt 1) demonstrates a peculiar anomaly in the data, it also clearly exemplifies a strategy that was not exceptional: *comparison* of abnormal and normal structures. Whereas some pairs mentioned the possibility as a joke, John and Pete were the only participants that actually asked whether the use of other Internet resources was allowed in the diagnostic process. After they were given permission, they used other online information sources extensively in order to find normal tissue samples for comparison.

Excerpt 5 (2nd)

500 John: ((Opens a normal gallbladder specimen from the course
501 materials.)) (0.6) ((Zooms in.)) (2.2) Well, but there now that (.)
502 necrosis because this is [now clearly…
503 [((Waves mouse back and forth along the 504 double line, 1st picture, Fig. 5.))
505 Pete: [Yes, it is very clearly this area.
506 [((Waves pen towards right, 2nd picture, Fig. 5))
507 (0.6)
508 John: Uhm. ((Moves to inspect the left side of the specimen.))
509 (5.2)
510 John: And (.) this [epithelium has probably been destroyed.
511 [((Moves mouse along the epithelium, 3rd picture, 512 Fig. 5))
513 Pete: [This cannot be seen either, yeah.
514 [((Moves pen along the epithelium, 3rd picture, Fig. 5))

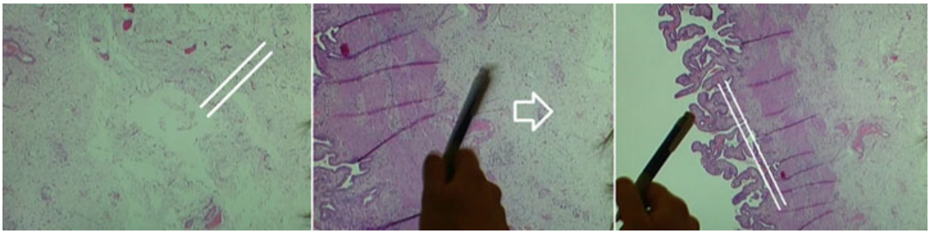


Fig. 5 On-screen actions marked with white lines and arrow

After opening the normal gallbladder specimen, the uncertainty that started to build up during and after Excerpt 1 is quickly resolved, John and Pete are able to agree on, and formulate almost simultaneously, diagnostically relevant findings (501–506, 510–515). Unable to solve the problem "on the spot", John and Pete extended the frame of reasoning to specimens of normal anatomy, which function as a shared point of visual reference and to make comparisons. The comparison with the normal sample makes it obvious that the epithelium is actually not abnormal but missing altogether from the sample being diagnosed, as evidenced by their simultaneous agreement and gestural references (510–515). Whereas John and Pete used external samples for their comparisons, other pairs relied on comparisons inside the sample they were diagnosing, for instance, by going back and forth between gallbladder tissues in order to identify the inner and the outer sides or by deliberately looking for normal tissue in the specimen for comparison.

The students' inspection of the slides is often guided by their *working hypothesis* of the diagnosis, a strategy illustrated also in Excerpt 4, and which is further demonstrated in the following:

Excerpt 6 (1st)
601 Jill: ((Slowly moving around the specimen with low magnification.))
602 Jill: Well, is there ulceration so if the hypothesis is, let's say, gastric
603 ulcer.
604 Joe: Yes or if one would find these little organisms ((laughs)).
605 (1.9)
606 Jill: [Yes, well, those are probably very difficult to see.
607 Joe: [Helico bacterium.
608 (3.1)
609 Joe: This is some other kind of staining ((points generally towards the 610 screen)), this is blue.
611 (0.7)
612 Jill: Oh yeah. Well, should we look with a higher magnification anyway 613 in case one could see those.
614 Joe: Right, what was it [look, wasn't it just like this some blue
615 staining…
616 Jill: [((Zooms in.)) (2.5) ((Zooms in further.))
617 Jill: Uhm. (1.4) Oh yeah! It is. ((Moves mouse cursor on helico
618 bacterium.)) (1.5) You're exactly right; those are helicos, those little…

Jill searches for ulceration based on her diagnostic hypothesis (602–603), whereas Joe, taking the colour of the sample as his point of departure (609–610, 614–615), suggests that they look for 'little organisms' (604): helico bacteria (607). Both inspect the slide to confirm or reject their hypothesis, which also directs their on-screen actions such as zooming and gestures. Jill reasons on the basis of her knowledge about possible diseases in gastric lining (a very prevalent form of reasoning in our data), while Joe argues on the basis of what could be called *contextual knowledge*, i.e., knowledge about the procedures behind the preparation of a microscopic specimen. He uses this knowledge to frame his interpretative work. Although not directly related to studies of anatomy or pathology *per se*, this kind of knowledge proved to be an important extension of basic biomedical or pathological knowledge required in the diagnostic process, as it organises and reshapes visual information (cf. Lynch 1985). The mechanics and techniques of tissue sampling were commonly discussed by the students. For example, they discussed how uterus scraping affects tissue structures, from which part of the organ and in what angle the sample was cut, the purpose of the use of different stainings as well as how this affects how cells and tissues show up in the sample, and often, whether a structural deviation in a tissue is pathological or just an artifact. Considering how strong influence such contextual knowledge had on how the specimen was interpreted (e.g., in Excerpt 4), the questions were not trivial to the participants.

The students seem to apply their theoretical and clinical (or practical) knowledge especially when *crosschecking* their observations with their hypotheses. By cross-checking, we mean the process of evaluating the coherence of the findings all the way from the sub-cellular level (e.g., helico bacterium) to the cellular level (e.g., lymphocytes), to the tissue level (e.g., atrophy), to the organ level (e.g., proximity of the organ that could be the origin of metastasis), to the patient level (background information) and their diagnostic hypothesis (e.g., the probability of male breast cancer). Whereas working hypotheses are used to find and generate new information, crosschecking is used in a more summative way, i.e., checking the coherence between known facts and preliminary conclusions. In Excerpt 7, Joe and Liz construct a coherent explanation of what they see on the cell and tissue levels in order to check their diagnostic hypothesis: cancer.

Excerpt 7 (2nd)

701 Joe: Also, there's a lot of lymphocytes [here, isn't there?
702 [((Circles mouse over cells.))
703 Liz: [Uhm (.) uhm.
704 (0.9)
705 Joe: Yes, [so it can also, it sure (.) belongs together with that cancer.
706 [((Zooms out)).
706 Liz: [Yes.
707 (4.3)
708 Liz: Okay (0.8) So it means that cancer has caused maybe necrosis here
709 [and so it builds this here.
710 [((Waves pen along the red tissue, Fig. 6.))
711 Joe: [Uhm.
712 Joe: Yes.

Having wondered for some time what '*it*' is, they bind 'it' together with the mechanisms of cancer, i.e., cancer has caused necrosis with lymphocytes, which further 'builds this here' (710). The causal relationship between levels is built by noting a cell level phenomenon with mouse gestures (701–702) and by subsequently widening the frame of reference with the zoom (706), after which the cell level information is connected causally with the tissue level by simultaneously uttering "here" and pointing to the area indicated by her pen (708–712).

Excerpt 8 illustrates a similar strategy of cross-checking used to decide whether an abnormality is only an artefact or a pathological finding.

Excerpt 8 (2nd)

800 Ann: If I then make a wild guess that that is a helico bacterium.
801 (0.6)
802 Eric: Are there then (1.5) cell mutations as well?
803 Ann: ((Zooms in.)) It doesn't, in principle, cause other than atrophy in 804 my opinion (.) or hyperplasia maybe
805 [but it can be that these are somehow…
806 [((Waves mouse cursor on the tissue, single white line, Fig. 7.))
807 Eric: [Doesn't it cause
808 (1.5)
809 Ann: The cause here is like this ((Points with mouse cursor, white
810 arrow, Fig. 7.)) (.) those
811 are like blood cells those (.) so in principle, if like… (2.0) So it could be 812 that it [leaks there because he had those stomach pains.
813 [((Moves mouse cursor over the tissue boundary, white double 814 line, Fig. 7.))

Uncertain of what they see, Ann proposes that it could be helico bacterium (800). Her explicit invitation to consider her proposition as a 'wild guess' triggers a process of cross-checking, in which this sub-cellular finding is crosschecked with what is seen on the cell level (802) and the tissue level (803–804). Ann reinforces her explanation with a physical metaphor (with a mouse) which illustrates the location and direction of the possible leak (813). Moreover, all of these are checked against the background information on the symptoms of the patient (812). Later on, the 'leak' is contested by Eric, who argues that it could be just an artifact caused by the mechanical process of collecting the sample. As the hypothetical leak fits well with their other findings and background information, it is finally accepted as a pathological abnormality.

Discussion

Our analyses showed how students used the technology as a mediating tool to organize, manipulate and construct a shared visual field and how they converged on a joint understanding of the problem and its possible solutions. Manipulation and organization of the visual field is done through multimodal referential practices (cf. Roschelle 1992; Roth 2000; Hindmarsh and Heath 2000; Alac 2008). Whereas physical gestures were present, mouse

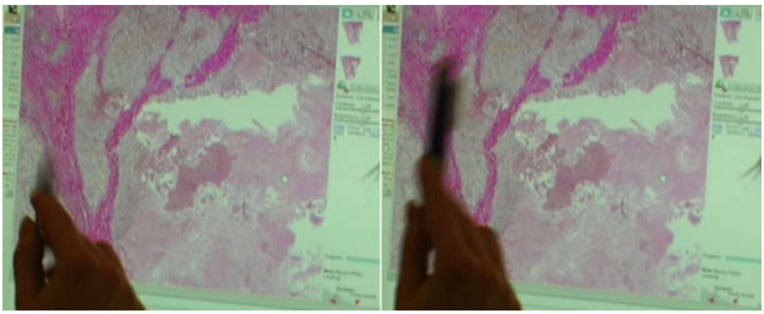


Fig. 6 Liz waves a pen to point at tissue that is causally related to the cell level

Fig. 7 Mouse cursor actions marked with white

gestures, three-dimensional manipulation of the image (zooming) and paced negotiations were at least equally important means of interacting. While the temporal organization is arguably important in any interaction, in our data paced negotiation arises as a prominent and fluid organizational structure. In conclusion, interactive application such as WebMicroscope dissolves the traditional distinction between collaborating around and collaborating through computers (Lehtinen 2003), and even face-to-face collaboration becomes embedded in, enacted through and contingent on the technology (cf. Alac 2008).

Furthermore, the aforementioned practices are intertwined with the students' diagnostic reasoning in this particular medical and learning context. Generally, the organisation of the visual information begins with framing of the diagnostic process, during which students highlight available background knowledge and orient themselves by identifying the major structures and dimensions of the specimen. Identification process continues with incrementally refined references (e.g., zoom and gestures) to specific areas of interest. This work was occasionally interrupted by disagreement, mutual uncertainty or by added attention to a visual cue. The visual cues were prepared in advance by a professional pathologist and exposed students to information that otherwise could possibly be ignored and demanded them to consider and comment on specific parts of the medical image. Yet, a visual cue alone without additional information or feedback remains relatively ambiguous. Depending on the context, this can be interpreted as either detrimental or advantageous to learning (e.g., Eva 2009; Pathak et al. 2011).

Disagreement and mutual uncertainties were dealt with by extending the frame of reasoning. Students used tentative working hypotheses to guide the collaborative interpretation process, hypotheses that are not necessarily based on the specimen, but on their medical knowledge such as probability of certain diseases. Similarly, the use of crosschecking and contextual knowledge exemplified how students verify tentative findings by checking their consistency in a larger frame of medical and technological context. The transitions across levels are also achieved and negotiated in interaction between the students and through the mediating technology that offers a platform for the discussion by enabling the employment of referential practices involving talk, gestures, zoom and pace. By describing the endogenous strategies students employ we hope to inform, firstly, how similar learning environments in medical or other contexts could be improved to support and develop reasoning that the students are already capable of, and secondly, how students are able to reach an agreeable understanding of the problem in collaboration in such environment. The issue of understanding the technological, and in our case, mechanical and biomedical, side of the image production has also been raised by Alac (2008). It entails distinguishing relevant signals from noise (cf. Koschmann and Zemel 2009), understanding of the capabilities and limitations of the technology (See Excerpt 4 where one participant raises the question if bacteria is visible in a light microscope?) as well as understanding of the significance of appropriate markers (in pathology, stainings). In contrast to simplified representations of the physical world, medical specimens are ambiguous and contain artifacts that cause students to wonder, justifiably, whether they can trust what they see.

The analysis of medical students' diagnostic work illustrates the collaborative potential of the virtual microscopy environment. Presenting the specimen on a computer screen enables fast, synchronous and collaborative examination of the slide. The activities students engage in do not deviate significantly from professionals in a similar situation (Alac 2008) and represent an in-depth engagement with pathology that requires mobilization of biomedical knowledge in diagnostic reasoning. Furthermore, paraphrasing Stahl and Hesse (2009), in order to engage in successful collaboration, participants must share a knowledge base, means of communication and/or language, and a joint focus and orientation. WebMicroscope facilitates this process of extending their reasoning by enabling a constitution of joint focus and a multimodal representation that can be manipulated in line with students' perceptions and assumptions. In terms of collaborative learning, Dillenbourg and colleagues (2009, p. 6) argued that the 'main categories of interactions have been found to facilitate learning: explanation, argumentation/negotiation and mutual regulation'. As shown by our analysis, virtual microscopy not only seems to facilitate all of these activities, but also how it is a constitutive element of such activities.

As mentioned at the beginning of this paper, the growing importance and diversity of medical imaging in everyday diagnostic practices, and thus, in medical education, raises a multitude of pedagogical questions. Considering the illustrated importance of contextual knowledge in students' reasoning and how it is framed initially, one such question has to do with the technical side of medical images. As technologies develop, knowing about the technical side of image production, or any visual representation, becomes an integral part of the interpretative process. Medical images are not neutral or perfectly accurate representations of biomedical phenomena. How these imperfections are communicated to the students may play a substantive role in how students learn to understand and interpret medical images. Moreover, we suggest that the endogenous practices and strategies described above can inform the further pedagogical development of visual tools in medical context.

Acknowledgments We are grateful to the developers and administrators of WebMicroscope, Dr. Johan Lundin and Dr. Mikael Lundin, for the technical support during our research. We also thank Dr. Raymond Bertram for his extensive comments on draft version of this paper. Finally, we are grateful to nurse Hannele Nysten whose practical assistance in organising the data collections has been invaluable to us.

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