Towards an Integrated Online Learning System for Microscopic Pathology: Two Teaching Examples

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Abstract

Microscopy is an essential basis for exploring and understanding pathological disease mechanisms. As a discipline, pathology is highly dependent on visual imaging technologies. Currently, digital pathology is a standard method with special advantages in both clinical histopathological diagnostics as well as the education of (undergraduate and postgraduate) medical students and pathology residents. However, to date, the available digital applications lack features to optimally support online collaborative learning and teaching of histopathology, such as possibilities for learners to individually perform tasks (e.g. annotate) on digital slides, opportunities for groups to reflect on their work and to receive feedback from more knowledgeable peers or supervisors. Such shortcomings have recently become more imminent, due to shifts toward more online learning in pathology education. Therefore, the *cLovid* (collaborative learning of viewing and decision-making skills) project set out to build an integrated online learning system featuring

- an open-source webmicroscope (an extension to the OMERO viewer) with enhanced features for annotating whole-slide images, allowing integration with assessment and feedback software;
- an online assessment software—e.g., VQuest, in our design—for constructing assignments using various types of responses (e.g. marker questions, which are ideal for visual domains), suitable for developing image interpretation skills through active learning with large images
- an open-source software dashboard (PRISMA) for synthesizing and visualizing students' responses in tasks using various types of responses, allowing teachers to provide collective feedback to groups of students, as well as a joint platform for communication for both on-site and remote settings.

Subsequently, the project team carried out two teaching pilots to demonstrate how this system can be used for teaching with guided activity, collaboration, feedback, reflection and possibilities for the teachers to model diagnostic reasoning. The teaching examples involved the pathology curriculum of second-year undergraduate medical students (N=70) in two European universities and the training of pathology residents (N=16) in Finland. In this paper, we present the development of the integrated system for online teaching and learning of histopathology and exemplify its use in the two scenarios. Lessons learned from the teaching pilots will be discussed.

Keywords

Collaborative learning, higher education, medical education, microscopy, online learning, pathology

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1. Introduction

In this paper, we present the development of an integrated online system for teaching and learning of microscopic pathology and exemplify how it can be used in two teaching scenarios involving undergraduate medical students and residents. Lessons learned from the teaching pilots will be discussed. Three tools form the core of the system: (1) a webmicroscope, (2) a software package developed for assessment with large images in medical education, and (3) a learning dashboard that synthesizes the responses of the users during assessment to enable collective reflection, dialogue and feedback. The integrated system constructed in the project is built upon existing software for digital microscopy [1, 2], and software that were previously used for another image-rich domain of medical education (i.e., radiology) [3, 4]. The current project looked into the needs of microscsopic pathology education and further developed the tools into a system to suit those specific needs.

2. Current trends in teaching histopathology

Pathology, as a medical discipline focused on the study of disease, has a central role in assisting students and doctors in their understanding of the mechanisms of diseases and their signs and symptoms, relevant for forming a differential diagnosis [5]. Magnification with different degrees and visualizing elements imperceptible to the human eye has been central to pathology at least since the invention of the microscope [6, 7]. And still today, microscopy is an essential tool for exploring and understanding histology and disease mechanisms [5, 8]. During recent decades, digital microscopy has emerged as a common practice alongside conventional optical microscopy [7, 9, 10, 11]. While early forms of digital microscopy relied on photographs or videos through digital cameras in microscopes [7], one of the key factors contributing to digital microscopy more recently has been the development of the whole-slide image (WSI), a scanned high-resolution replica of a glass slide [12, 13]. Once scanned, WSIs can be interpreted with a regular laptop and suitable software. Currently, digital pathology is a standard method with special advantages for both clinical histopathological diagnostics as well as for the education of (undergraduate and postgraduate) medical students and pathology residents.

Both optical and virtual pathology have their advantages and disadvantages [10, 12]. For educational purposes, digital microscopy [11, 14, 15] and WSIs in particular [9, 12, 13, 16, 17, 18, 19, 20] have many advantages for both on-site and remote teaching of pathology. A demonstrative histological specimen can be scanned, and the resulting WSI shared for interpretation among an entire class in which the image interpretation skills of each individual can be assessed on identical material. In addition, teachers can annotate WSIs of tissue samples to instruct large groups of students with worked-out examples or ask students to annotate the images themselves in assignments. Additionally, as digital microscopy does not require conventional laboratory environments, it allows teachers new possibilities for designing online or blended learning environments [21, see also, 22].

During the COVID-19 pandemic, conventional ways of teaching microscopic pathology on-site were not possible. With forced social-distancing, teachers had to redesign their courses and invent unconventional learning environments to accommodate the situation [21, 23, 24, 25]. This emergency remote teaching led to a “dramatic and significant increase in the use of digital pathology-related education tools” [25], and thus opened new avenues for developing histopathology education. While searching for creative solutions to sustain their teaching during the period of social-distancing, many teachers became aware that digital applications lack features to optimally support online (collaborative) learning and to teach histopathology in an online environment. Such necessary features included possibilities for learners to individually annotate digital slides, to receive feedback, and opportunities to reflect on their work, among others.

Therefore, the *cLovid* (collaborative learning of viewing and decision-making skills) project set out to build an ***integrated online learning system for microscopic pathology education*** to address these shortcomings. Through this work, we also made the tools (online webmicroscope with added features and a learning dashboard) of this system available to the community [see, 26], including supporting material (such as documentation, video tutorials, and demo data) and teaching content (such as tasks and WSIs).

3. The integrated learning system and its components

The integrated online system consists of the following three components:

- an open source webmicroscope (an extension to the OMERO viewer) with enhanced features for annotating WSIs, allowing integration with assessment and feedback software;
- an online student assessment software package (e.g., VQuest) for constructing assignments in order to develop image interpretation skills through active learning with large images.
- an open-source dashboard (PRISMA) for visualizing students' responses in order to provide collective feedback to a group of students and a joint platform for communication, for use in both on-site and remote settings.

The system is inexpensive, because the webmicroscope and the dashboard can be used free of charge. The VQuest software can also be replaced by another assessment or e-learning package, based on the provided documentation on how to incorporate the adapted OMERO viewer into another system. Neither the teachers nor the students need to install anything, since everything can be operated through a browser. Figure 1 outlines the core characteristics of the three components of the system. Together, they can be implemented on-site or online, through any video conferencing tool.

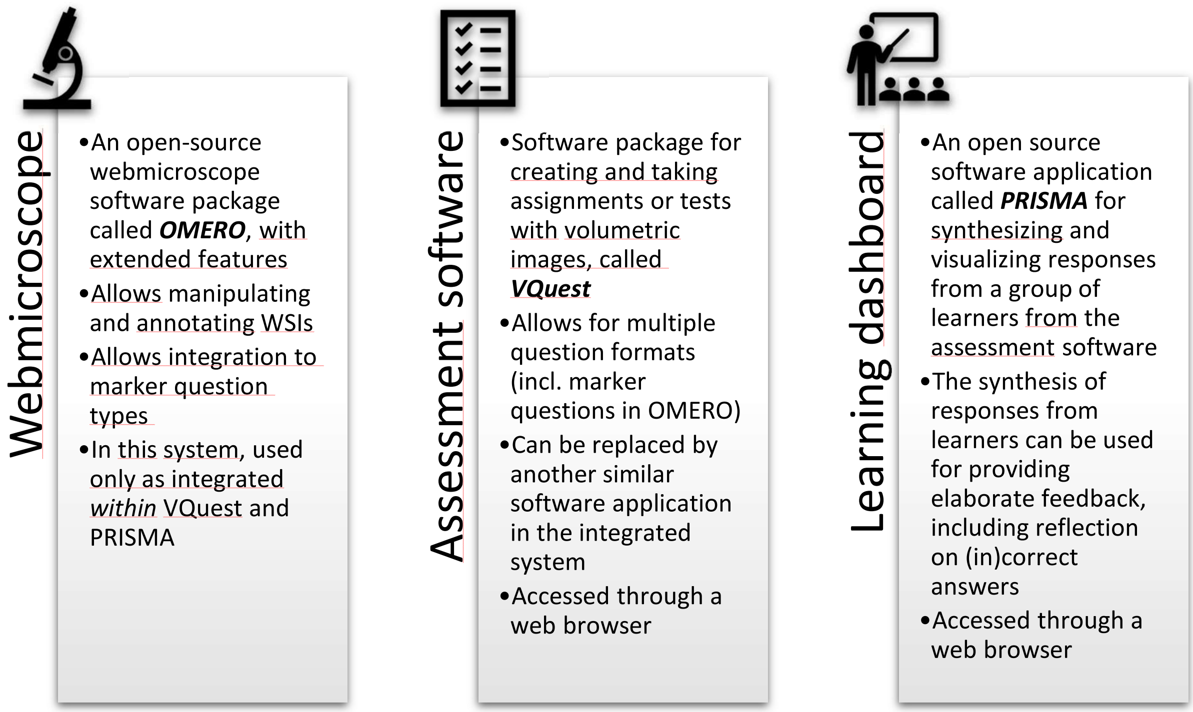

Figure 1: Summary of main characteristics of the three components of the integrated online learning system

3.1. Webmicroscope

In the beginning of the project, the team conducted a needs analysis regarding functionalities of a web-based WSI viewer [27]. Key stakeholders (i.e., likely users) of the system were approached about the general and specific functionalities they considered more or less important for microscopic pathology education. Responses were from both teachers (n=17) and students (n=4). Based on this input, a synthesis of relevant functionalities was formed. Regarding general functionalities, most respondents considered zoom overview, fluent zooming, and panning of images as essential. Many also considered the possibility to show multiple images simultaneously valuable, as well as being able to control the visibility of specific annotations. In addition, the responding teachers and students also indicated a need to use full screen and a wish to keep the number of (sub)menus limited (since they do not leave enough space for images). Regarding specific functionalities, most considered the following as something the viewer either “must have” or “should have”:

- Denoting or highlighting specific structures
- Creating marker questions
- Creating multiple marker questions
- Asking students to identify or describe marked areas
- Overriding student choices in the visibility of annotations

To address these needs for online viewing and manipulation of WSIs in our integrated online learning system, we adopted the open-source *OMERO* viewer [1, 2]. The viewer has been adapted so that no additional login is needed to get access to the image data (single sign-on), because the images themselves are stored on a separate OMERO server. All the images used were converted to the ome.tiff image format [2], which is the standard for storing WSIs on an OMERO server. Manipulation of the images was supported (e.g. zooming, panning, rotating), with an additional option to show the WSI at full screen mode for best viewing possibilities at large scale. The WSIs will finally be hosted on an OMERO server of the ‘Imaging Network’, a cooperation network of the central scientific institution at the University of Münster that promotes and supports cooperation among scientists in the fields of cell dynamics and imaging across working groups and faculties. Although this OMERO server is originally meant for research purposes, the ‘Imaging Network’ has enabled the cLovid-project to offer a limited collection of images together with the adapted viewer specifically for educational purposes.

Apart from standard question types (such as multiple choice, multiple alternatives, and open questions), the so-called marker question was considered most helpful. With this truly interactive question type, candidates are asked to place a marker in a WSI, which is configured as an arrow pointing to a specific structure. The arrow can easily be adapted by clicking and dragging with the mouse. In the same image, the teacher can annotate one or more structures to indicate the correct answer, e.g. multiple cells or areas. Moreover, for the group discussion, multiple marker answers can be visualized simultaneously to show the arrows of multiple individuals or groups of students in the online dashboard. To this end, we added support for the teacher to turn on/off certain answers in the OMERO viewer.

3.2. Assessment software

The second component relevant to our integrated learning system is software suitable for designing tasks and assessing student performance with volumetric images. We opted for *VQuest* (see, Figure 2), a software package developed at the Image Sciences Institute at the University Medical Center Utrecht [28]. VQuest combines an authentic viewer for medical image manipulation (e.g., zooming, panning, contrast enhancing, and scrolling) with a set of tools for developing and taking test items. The test items include several question types, such as commonly used open-ended and multiple-choice questions. In addition, VQuest also allows for “long-list menu” questions, which only allow responses from a given range of diagnostic terms. Since this range can be a very extensive list—compiled by teachers or test developers—these questions can still be marked automatically with a negligible chance of guessing. Finally, VQuest also allows for marker questions to be used in the integrated OMERO webmicroscope. Thus, students can be asked to place markers in an image to indicate a certain structure or pathology, and the placed markers can be aggregated from different users into a single interactive visual representation.

3.3. Learning dashboard

A learning dashboard called *PRISMA* (see, Figure 3), developed to facilitate activating in-class scenarios in radiology education [3, 4], was adapted for microscopy education and used by the teachers during the online plenary sessions. A learning dashboard is an “application that captures and visualizes traces of learning activities in order to promote awareness, reflection, and sense-making.” [29] and thus all participants can simultaneously see the specific choices made by different students or groups of students. The aim was that awareness of everyone's contributions would encourage reflective dialogue in both small-group collaboration and plenary discussions.

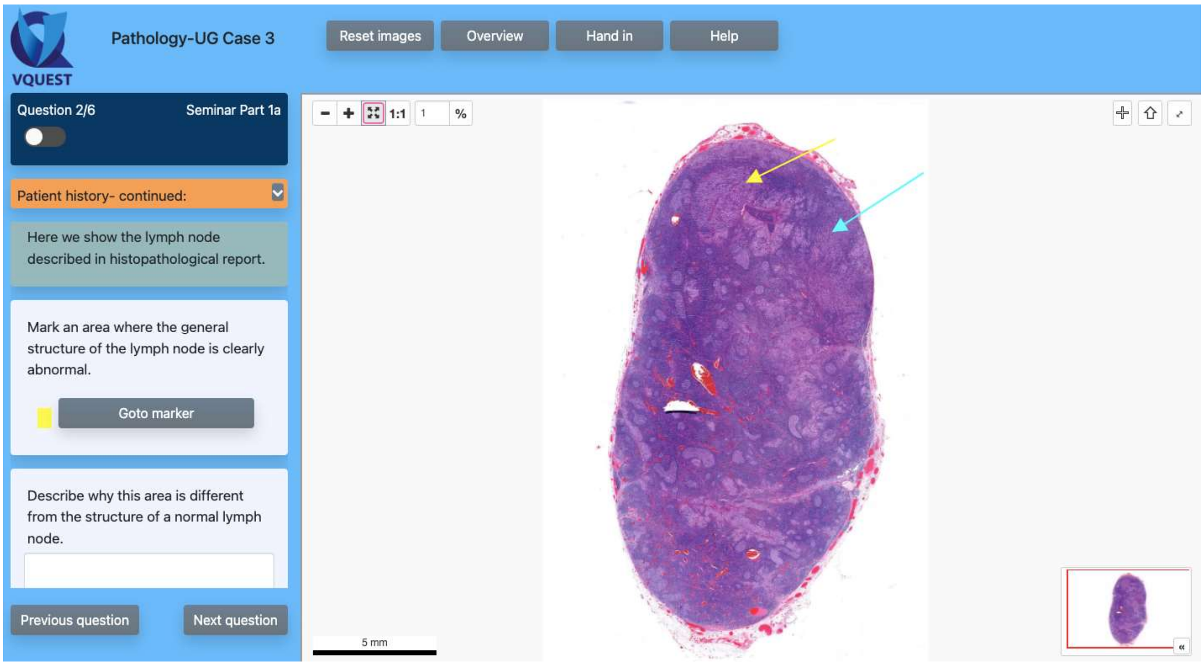

Figure 2: Student interface of VQuest with the OMERO microscope, showing an example of a marker question (in which students are asked to mark locations in the microscope) and an open-ended question (in which students are asked to describe their reasoning for choosing a location).

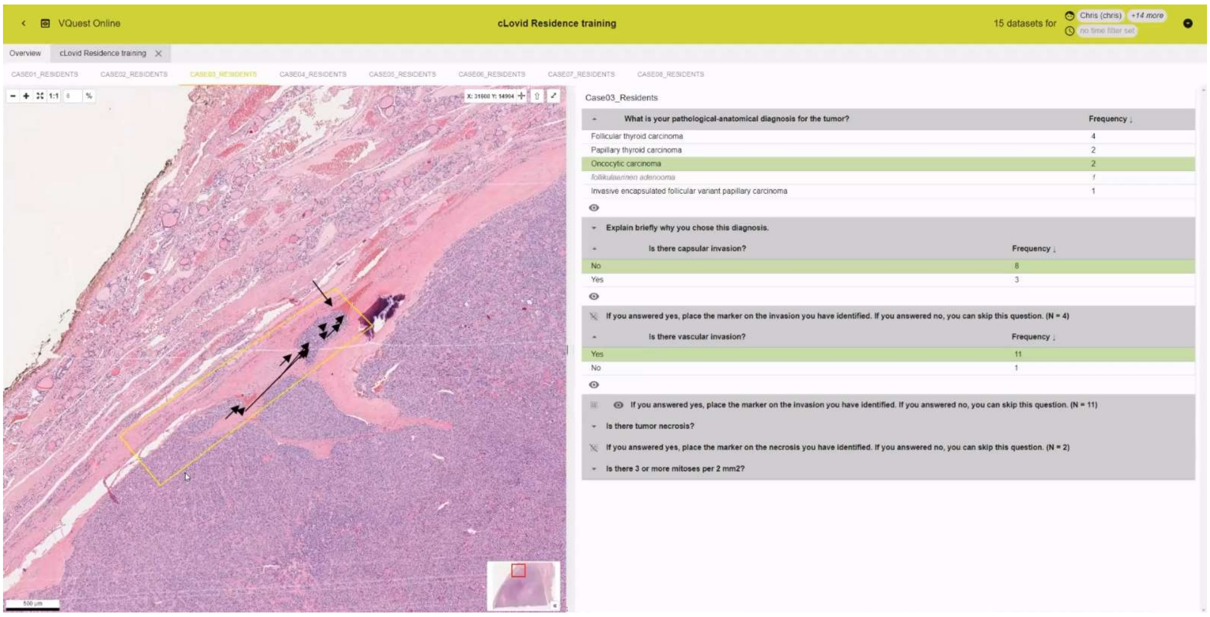

Figure 3: Screenshot of PRISMA with the OMERO microscope: the arrows represent student responses to a marker question; the correct answers are in the rectangular area.

3.4. Designing blended learning using the integrated system

During the initial phase of learning in many disciplines, novices are often faced with a large array of facts, concepts, and seemingly isolated pieces of information. In pathology—as an image-rich discipline of medicine, there is the additional challenge that one must at the undergraduate level make distinctions and identify features differing from normal histology, and in residency training make diagnostic interpretations based on large amounts of visual material. Unlike histopathology specialists, students and trainees often resort to focusing on details and the memorization of facts using any pre-existing schemata to make sense of isolated pieces of information.

Decades of work has investigated how to build learning environments that promote meaningful learning (i.e. learning for understanding). In this work, we build on insights based on interactive multimodal learning environments. In a multimodal learning environment, students operate with content in both verbal and non-verbal modes [30]. Interactivity, in turn, has been conceptualized in many ways [30, 31, 32], and is referred to here in the sense of the range of multidirectional communication between the learner and the learning environment (e.g. computer software, teacher, other learners, and/or social settings). Centrally, educational activity among the students, and between the students and the teacher, comprise an important aspect of interactivity in instructional systems. Interactivity with the digital tools can include activities such as manipulating (e.g. the student moves or edits objects on the screen) and dialoguing (student receives questions and feedback based on responses) [30].

Moreno and Mayer [30] identified five empirically tested instructional design principles that apply to interactive multimodal learning environments. The first principle *Guided activity* states that it is better to prompt learners to engage in a task with appropriate guidance (with a pedagogical agent) and feedback instead of merely exposing them to direct teaching. The second principle *Reflection* implies that when asked to reflect upon their actions during the process of meaning making, learners are encouraged to more actively organize and integrate new information. The third principle *Feedback* emphasizes the need for explanatory feedback (i.e., feedback that provides justifications for the relative success of given answers), rather than corrective feedback alone. Fourth, *Pacing*, highlights the role of learners in controlling the pace in which instructional materials proceed. And finally, *Pretraining* asserts that focused pretraining can set way for better learning by providing or activating relevant prior knowledge.

4. Piloting the environment

The present study incorporated the following instructional design principles into each teaching pilot: *guided activity* (i.e. students' active engagement with learning materials before being presented "the canonical explanation"), and an opportunity for *reflection* and elaborated *feedback* on the answers given (final seminar). The pilot designed for undergraduate students also included *pretraining* in the form of self-study of online materials and completing exercises related to the materials. Table 1 summarizes central aspects of the two teaching examples.

4.1. The Resident pilot

The first, so called resident pilot, was organized in January 2023 in the context of Finnish national pathology specialization training. The basic idea of the pilot was to help the residents to prepare for the national specialization examination. The pilot involved preparatory work and an online debriefing session. The preparatory work for the online seminar consisted of eight patient cases presented as digital tissue samples and a variety of question types (free text, multiple choice, marker, and long list) in VQuest. All responses were collected and visually displayed in the PRISMA learning dashboard during a debriefing session via Zoom. A total of 16 residents completed the VQuest assignments, of which eight also participated in the final online debriefing session.

Based on preliminary examination of participant ratings on a scale from 1 ("does not apply at all") to 7 ("applies very much"), it is safe to conclude that the participants considered that the training met its objectives. Residents felt that working individually with the eight patient cases in VQuest helped them to prepare for the national examination (M=6,1; sd=0.99). Likewise, they were of the opinion that the online debriefing session was good preparation for the examination (M=6.0; sd=1.33). When asked if they would like to continue preparing for the national examination in a similar way, the response was highly positive (M=6.57; sd=0.79). The only aspect that left scope for improvement was the lack of teacher-resident interaction in the debriefing session. Based on the recording of the session, contributions from the audience were minimal despite the teachers support and encouragement.

Table 1
Summary of core details about the two teaching pilots with the integrated online learning system

	Pilot I	Pilot II
Participants	8 pathology residents from different universities within one country	70 undergraduate medical students from two universities in different countries
Time for teacher preparation for feedback session	~2 weeks, well-prepared feedback	None, spontaneous feedback
Timing and length	Two sessions: first residents' individual work (1–2 h) with VQuest, and a plenary feedback session (2h) ~2 weeks later	One session
Purpose of the teaching	To serve as training opportunity for the final examination in pathology	Capstone online seminar in an elective course in clinical pathology
Pretraining	No pretraining	Pretraining with online learning materials and two assignments
Interaction during session	There was interaction between the two teachers, but despite teacher prompts to ask questions, there were no questions from the participants. (Overt teacher-student interaction was low; no interaction among the learners)	Students were presented with a new clinical case. They explored the case in two parts in small groups in break-out sessions (Zoom) and documented their responses in VQuest. The online interaction (teacher-student; student-student) was substantially higher than in the past.
Main teaching activities during the session	Interestingly, the other teacher only made use of open questions, whereas the other teacher made more use of the affordances of the integrated system (e.g. marker questions). The teachers elaborated on the responses (incorrect responses and correct ones) of the participants.	Visiting the break-outs rooms (monitoring and social presence); asking the small groups justifications during the subsequent plenary session; providing a histological summary of the case

4.2. The undergraduate pilot

The second, international undergraduate pilot, was organized in February 2023 in the context of an elective course focused on clinical pathology in two European universities: one in Finland (n=37) and another in the Netherlands (n=33). The shared learning objectives were: 1) understanding the principles of malignant processes at the level of the organism, tissues, and cells, and 2) understanding how cell and tissue abnormalities influence the prognosis of the malignant disease. To begin with, all students were given the opportunity to prepare themselves by studying a set of online self-study materials prepared by the project team and to complete two patient cases in VQuest individually. In the collective part of the pilot, a total of 70 students and two pathology teachers from both universities took part in the teaching pilot, which culminated in a three-hour online seminar. This session was based on the notion of computer-supported collaborative learning featuring one patient case, which was first elaborated upon in small groups through break-out sessions (see, Figure 4).

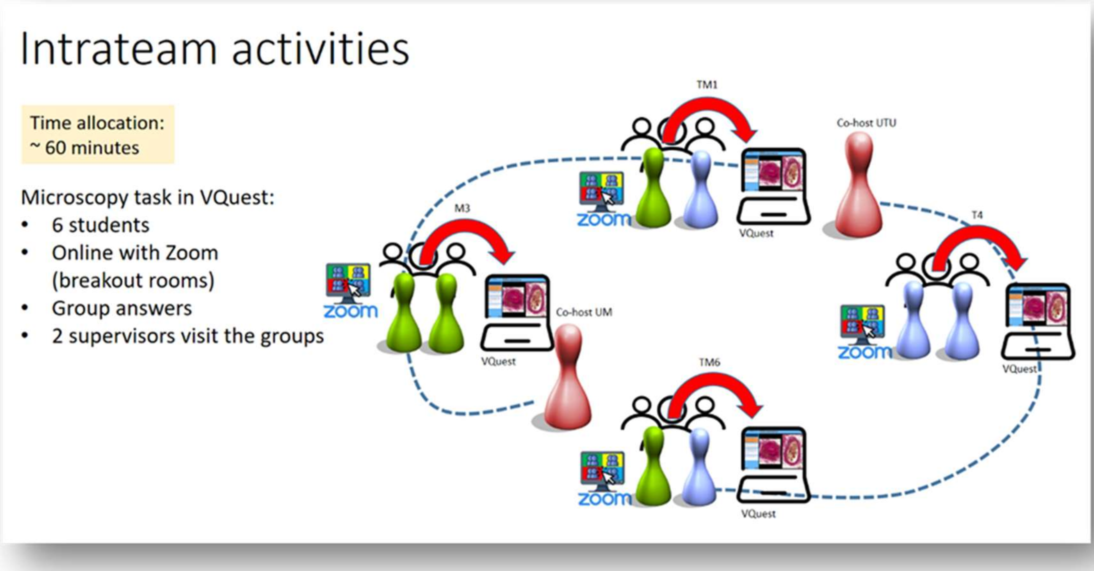

Figure 4: The design of intrateam activities for the undergraduate pilot

During the break-out sessions, one student from each small group acted as an "operator" who logged into VQuest, and shared the screen for other group members, who could then collaborate on reasoning and collectively advising the operator. After the intrateam activity, teachers led plenary sessions to jointly discuss the topics arising from the patient case and interpreting the histological specimen (see, Figure 5). The aim of the joint sessions was to discuss the differential diagnosis and clinical reasoning in the patient case.

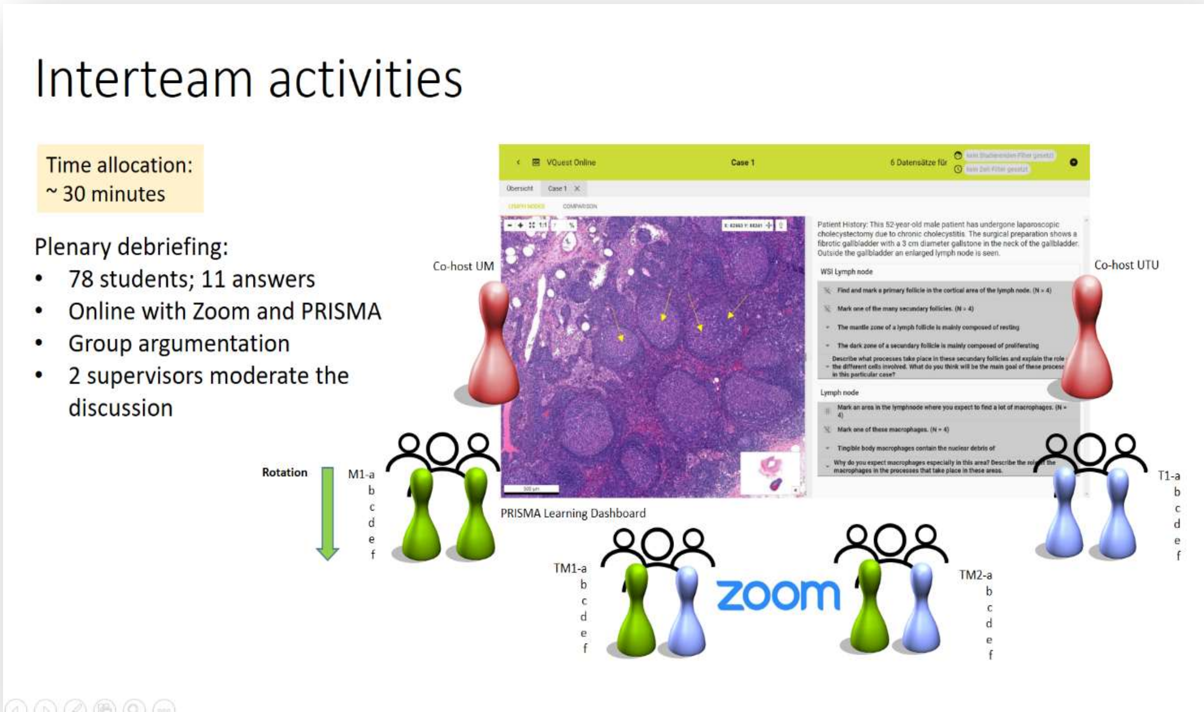

Figure 5: The design of interteam activities for the undergraduate pilot

All of the Finnish participants granted consent to use their feedback for research purposes. The students' appraisals on five Likert scale items, are summarized in Table 2. The self-study exercises in VQuest received the highest score on average (M=3.86). Open-ended responses showed that many students enjoyed discussing the cases, especially if the group as a whole was very active. The students also expressed appreciation for the teaching in the plenary session. On the downside, time management was criticized – "less instructions, more action" – since the online seminar finished half an hour late on a Friday afternoon. Some students pointed out that the case discussed in the final seminar lacked challenge while the cases in the self-study materials were considered more intriguing. The project team feared the students would complain about the vast amount of self-study material, but students appreciated the "compactness" and structuring of the materials, and the opportunity to explore even further. To facilitate interaction and due to functional reasons, only one student of each group had access to VQuest, and this raised dissatisfaction in at least one respondent.

Table 2
Participant appraisals (Likert 1-5) of the undergraduate pilot: valid n, minimum, maximum, mean and standard deviation

Variable	*n*	*Min*	*Max*	*M*	*SD*
Usefulness of self-study materials	37	2	5	3.59	1.01
Usefulness of self-study exercises	37	2	5	3.86	1.06
Too much time needed for self-study	37	1	4	1.92	0.83
Online seminar: a good learning experience	37	1	5	3.08	0.80
Online seminar: enjoyable	36	1	5	3.28	0.97

5. Discussion and conclusion

The purpose of the article was to present the development of the integrated system for online teaching and learning of histology and exemplify its use in the two teaching scenarios. Learner appraisals of the resident pilot were very positive and the appraisals of the international undergraduate pilot were encouraging. In addition, it was evident that several instructional design principles of meaningful learning could be easily incorporated into the teaching.

As mentioned above, several instructional design principles for interactive multimodal learning environments [30] were incorporated into the integrated online learning system. VQuest with OMERO provided a platform for guided activity with tasks each learner had to complete before participating in a final seminar. Teachers provided elaborate feedback on correct and incorrect answers during both of the seminars. Addressing the range of incorrect responses, teachers acknowledged the possible ways of reasoning behind them but refuted [33] them through biological and clinical facts. Overt reflection was facilitated in the undergraduate pilot by the interactive small group setting and by the teacher prompting the student groups to justify their responses. In addition, the recording of the resident pilot was segmented after the session and shared with the participants to enable them to review the materials afterwards at their own pace. Because the main goal of the resident pilot was to mimic the national specialization examination, only the undergraduate pilot provided pretraining.

In the undergraduate pilot, students did not have the possibility to opt out: everyone was expected to take part in the seminar. As a result, some students expressed frustration because, in their opinion, the patient case was not challenging enough. Thus, in future scenarios, teachers might consider using parts of the integrated system for meaningful differentiation in order to alleviate such frustration. For example, if the students were given the opportunity to show mastery of the content and diagnostic skills beforehand (e.g. with a case in VQuest), some students could be exempt from participating in the seminar, resulting in a more homogenous, and less frustrated, group of students.

From the viewpoint of pathology teachers, the implementation of the pilots indicated that the developed web-based educational system can be applied in varying ways in very different settings. In the resident pilot, teachers had plenty of time to acquaint themselves with the learner responses. Instead in the undergraduate pilot, the teachers began the feedback discussions immediately after student groups had finished work in their breakout groups, thus giving the teachers no time to dive into the range of responses beforehand. The latter approach might suit better experienced than inexperienced teachers. Likewise, reflecting and giving feedback for student responses without prior orientation with the responses might better be suited for scenarios involving common misconceptions and misunderstandings. In situations in which even the teachers themselves are only learning about the range of possible misunderstandings (e.g., when dealing with a new kind of case for the first time with students), one might instead design the learning sequence in a way that allows the teachers enough time to study the student output, and thus making a better planned reflective discussion (e.g., with prepared refutations possible.

The pilots differed considerably in the amount and quality of interaction during the sessions. Designed specifically for computer-supported collaborative learning, students in the international undergraduate pilot interpreted the given samples and solved the related tasks together in small groups. They were also prepared to justify their answers in the plenary session during which teachers challenged the students to discuss the case. In the resident pilot, on the other hand, there was hardly any interaction among the participating residents, despite teachers prompting discussion. The only visible participation was in the Zoom chat. This may be explained by the fact that the session was named, framed, and introduced in a way that did not invite active participation. Another possible explanation is that residents were promised anonymity in their test responses. Whereas teachers in the undergraduate pilot asked the students to elaborate the exercises, in the resident pilot they needed to provide the reasoning themselves. On the other hand, anonymity can provide safety for the learning environment—especially for students uncertain of their knowledge. Thus, the decision about (the degree of) anonymity is something teachers should consider well before implementing scenarios. Yet, even with anonymity, dialogue about different responses and the possible false beliefs or misconceptions behind them should be possible. Only in such scenarios, teachers might motivate the discussion, not by inviting students with (in)correct responses to identify but instead, by asking about relevant factors that essentially mediate decisions for accurate diagnoses.

Interestingly, at the outset, teachers had different expectations regarding the integrated online learning system and varying preferences related to the kind of tasks they saw valuable for their teaching. This was most evident in the resident pilot where the two teachers chose different approaches for the demonstrated patient cases, varying from only text-based items (long-list menu and open-ended questions) to marker questions alongside text-based items. Our experience indicates that a clear advantage of the marker questions is that they allow teachers to visually present the range of (in)correct or more-or-less correct responses and quickly navigate exactly to those parts of the image the learners have had in mind while interpreting the sample.

Finally, we wish to point out that due to the dramatic increase in clinical demand for diagnostic, prognostic, and predictive assessments, diagnostic specialties—pathology among them—struggle with labor shortage, and recruitment of next generation pathologists remains a concern. Concerning undergraduate education, early exposure to digital pathology has been shown advantageous for students to gain understanding of disease mechanisms, and pathology as a clinical practice [20]. Thus, digital pathology and web-based pathology education may also serve to attract the interest of medical students with the intention to facilitate interest in residency and motivate them to pursue a career in pathology [34].

More in-depth study of online collaborations within the presented system could in future be carried out by a quantitative analysis of the logged responses in the assessment program VQuest or by a more qualitative interaction analysis of recordings of the group discussions in the Videoconferencing program. In terms of learning analytics, as the learning dashboard receives the data from the assessment systems in a standardized form, the learners' data can be mapped relatively easy to a specification like xAPI which then enables further developing powerful learning analytics. Taken as a whole, the successful implementation of the first teaching pilots using the novel integrated online system for the teaching and learning of microscopic pathology alongside the learner appraisals of the digital tools, materials, and the learning scenario provide initial proof of concept.

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