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Analysis of intended learning outcomes and evaluation of teaching activities in practical courses on microscopy

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Introduction

The cell and the processes taking place therein are at the center of today's biological science. Among the tools available to study cells, microscopy stands out, because it is the only technique that can make the micrometer- or nanometer- sized objects visible to the human eye. Therefore, microscopy training is an essential part of every study program within life and medical sciences. In recent years, there has been a trend to replace hands-on training using actual microscopes with "virtual microscopes" (Schwartz 2005), computer programs in which the function of a microscope is simulated. This has happened primarily at medical schools, but the high cost of the infrastructure that is needed for hands-on training also causes biology departments to consider switching to "virtual microscopes". It is therefore timely to investigate how microscopy techniques can be taught most efficiently.

In this study, different teaching activities (TAs) that are currently used for microscopy training of students will be assessed regarding their value for the realization of intended learning outcomes (ILOs). The first part aims to clarify whether there are differences between the ILOs of different microscopy courses taught at Danish Universities. Understanding differences in ILOs is a precondition for the general assessment of microscopy-related TAs. In the following part, the potential of virtual microscopy for microscopy-related courses will be assessed qualitatively by interviewing experienced lecturers. This part aims to advance the debate on which learning outcomes can be realized with "virtual microscopes". In the last part, the value of different teaching activities for realizing a course's ILOs from

a student's perspective will be investigated. Course evaluations are used to find out which teaching activities are critical for the successful implementation of a practical course in microscopy.

Method

Analysis of intended learning outcomes of microscopy-centered courses

Course databases of all major Danish Universities were searched for microscopy-centered courses. Information on the ILOs was obtained from the course descriptions as found on the internet. The following courses were included in the analysis: "Electron microscopy" (*University of Copenhagen* 2014*a*), "Light microscopy - Advanced methods in microscopy" (*University of Copenhagen* 2014*b*), "Confocal laser scanning microscopy" (*University of Copenhagen* 2014*b*), "Scanning electron microscopy" (*University of Copenhagen* 2014*b*), "Electron microscopy and analysis for materials research" (*Technical University of Denmark* 2014*a*), "Ph.D. Summer School on Methods in Imaging and Energy Material Microstructure" (*Technical University of Denmark* 2014*b*), "Stereology" (*Aarhus University* 2014), "Nano-optik" (*Technical University of Denmark* 2014*c*), "Biophotonics" (*Technical University of Denmark* 2014*d*), "Principles Light and confocal microscopy" (*University of Denmark* 2014), "Molecular Biophysics – Fluorescence microscopy and surface-sensitive techniques" (*Center for Membrane Physics* 2014), "Fluorescennsteknikker for biomolekyler og celler" (*Southern University of Denmark* 2014).

All of the above courses are taught at graduate level. Undergraduate courses, even when they include teaching in practical microscopy do generally not address this skill in their ILOs, as they are only subject-focused. In order to get information on microscopy-related ILOs of undergraduate courses that include acquisition of microscopy skills, the teachers responsible for the course in question were asked.

Assessment of virtual microscopy

The viewpoints and comments of two experienced University lecturers working at the University of Copenhagen were considered. Prof. Alexander Schulz from the Faculty of Science teaches general cell biology courses

for Bachelor students in biotechnology and veterinary sciences programs. Clinical Prof. Ben Vainer from the Faculty of Health Sciences teaches the introductory course in pathology for medicine Bachelor students.

Their experiences with and virtual microscopy and their opinions were collected from interviews and contributions to the University newspaper "Universitetsavisen" (Fjeldberg 2014, Vainer 2014, Schulz 2014).

Student evaluation of teaching activities

Relevant information was obtained from the anonymous evaluation sheets for the graduate-level course "Advanced Methods in Microscopy" for the years 2012, 2013 and 2014. Students attending the course have different study backgrounds, but the average competence level was similar in all years according to the responsible teachers. The students that participated in the course were asked to fill out the evaluation sheet on the last course day or within one week after completion of the course. The participation rate was 80% in 2012, 74% in 2013 and 75% in 2014. Between 16 and 20 students participated each year.

Results

The intended learning outcomes of microscopy courses differ in the degree of practical skills to be conveyed

Teaching activities can only be evaluated in light of the ILOs that they should help to achieve. Therefore, in order to analyze TAs for the transfer of microscopy skills, the actual ILOs of microscopy-focused courses have to be clarified.

The analysis of 12 courses that have microscopy as their main focus shows that the transfer of theoretical knowledge regarding a respective microscopy technique is the most common aim, since it is stated as an ILO in 100 % of the course descriptions (Table 2.1).

Differences can be seen with regard to the degree that the student should be able to handle the microscopes independently. Only 42% of the courses define this as an ILO. In contrast to that, most courses aim to put students in a position where they can compare different methods and identify the most suited for a given sample (83%) and, extending this point, where students can formulate an imaging strategy for a given sample (58%). It can also

be noted that most courses operate with standard samples instead of the student's own samples, which only 17% of courses refer to in their ILOs. However, discussing microscopy techniques suited for the student's samples is at least an ILO of 42% of the courses.

Table 2.1. Intended learning outcomes of 12 microscopy-centered courses taught at Danish Universities.

Intended learning outcome: students should be able to…	Percent
show theoretical understanding of respective microscopy method	100
compare different methods to identify most suited for a given sample	83
formulate imaging strategy for a given sample	58
use respective microscopy method independently	42
discuss microscopy techniques suited for their own samples	42
use microscopy data in further applications	33
optimally analyze their own samples	17
fulfil other method-specific ILOs	*42*

It can be concluded that while all courses intend to convey the theoretical background and to show students what techniques are available and when they could be used, only a subset of courses actually intends to teach practical skills that lead to independent usage of the respective microscope.

This has important implications for the employment of different TAs. Extended hands-on time, for example, might not be required for courses that do not aim to make students independent users of the microscope.

Undergraduate courses are not included in the table because they generally do not relate to microscopy skills in their ILOs. Asking lecturers and study program coordinators revealed a similar trend as described for graduate courses above, i.e. some courses do intend to teach practical skills, like "Methods in molecular biology" in Copenhagen University's Biotechnology Bachelor program, while most courses only focus on understanding microscopic images.

Virtual microscopy is not suited to teach skills related to practical microscopy

The analysis of ILOs of microscopy-focused courses showed that the main intention of many courses is not necessarily to educate the students to independently operate a specific microscope. Instead, the main learning goal is

that students know which research questions can be solved with it and what requirements have to be fulfilled. In these cases, can virtual microscopy be an appropriate tool? This question is answered here by assessing the arguments of two University teachers that have opposing opinions on the value of virtual microscopy. It should be noted that the economic aspect that favors the use of virtual microscopy is disregarded here, since only its effectiveness for reaching microscopy course ILOs shall be assessed.

Dr. Ben Vainer, clinical professor in general pathology established virtual microscopy at Copenhagen University's Faculty of Health Sciences (Fjeldberg 2014). He sees the following advantages compared to conventional microscopy. For large classes, the laborious sample preparation, which was necessary before, can be omitted. Furthermore, learning is not hindered by problems associated with microscope operation and there are no sub-optimal samples. In addition, students can access images from home, allowing for more flexibility in using this TA. He received positive feedback from students, but has not evaluated if the student's performance in the respective exams improved (Vainer 2014).

Dr. Alexander Schulz, professor in cell biology at Copenhagen University's Department of Plant and Environmental Sciences, stresses the advantages of conventional microscopy. In his experience, it is a great teaching tool from a pedagogical viewpoint. Using the microscopes involves the students actively in the learning and provides a change from the student's focus on a lecture or computer screen (Schulz 2014). Moreover, students get valuable experience with variable sample quality that is not possible by only seeing optimal slides. It also provides an opportunity for direct interaction between supervisors and students that can be beneficial for the learning experience. Furthermore, he made the experience that actually using research tools like microscopes kindles the interest of students in doing research, encouraging them in their research career path.

In Dr. Vainer's teaching setting, the effort associated with the use of microscopes is distracting the students from learning about medical conditions (Vainer 2014). In other words, the advantages of virtual microscopy are most relevant in courses where microscopy as a technique is not part of the content. This is also true for the cell biology courses taught by Prof. Schulz. Nevertheless, he uses conventional microscopy, because it is a more valuable TA compared to virtual microscopy in his experience. In this way, both teachers actually agree that virtual microscopy is a tool to teach microscopy-related content without the need to discuss the technique itself.

What does this mean for the present question whether virtual microscopy is a suitable tool for courses with the aim to teach students theoretical background of a specific microscopy technique and how it can be applied? Two arguments against the use of virtual microscopy in this context are brought up by Prof. Schulz. One is that without seeing samples of varying qualities, students cannot judge what kind of images can be produced with a certain microscope. As Prof. Schulz says: "Students have to get an eye for the quality of a sample. Because of the fact that the course organizer is preselecting the best slides, the students lack to get trained in this judgment" (Schulz 2014). Even though the ILOs of the courses in question do not involve independent operation of microscopes, they do include the ability to judge the potential of a specific microscopy technique. This ILO cannot be realized by using virtual microscopy.

The other argument is that without handling microscopes, students do not learn how much time and effort is required to produce a good image with a given microscope (Schulz 2014). This limits their ability to judge if this microscope is suited to solve a specific research question. This means that virtual microscopy also limits the possibility of achieving the ILO of being able to develop imaging strategies and choosing the most appropriate microscope technique for a given sample.

Hands-on time has to be balanced with extensive theoretical explanations for successful teaching of microscopy handling skills

In order to assess the value of different TAs for a microscopy-focused course, student evaluations of one course that is taught in every year were analyzed. The course ILO specifically include that students should learn to operate the microscopes independently. Therefore, a large part of the course is dedicated to hands-on time during which students, in groups of two, use different microscopes. They analyze samples that they prepare themselves according to instructions in the course manual. The hands-on part is complemented by a theoretical introduction and a journal club. The students have to prepare a report that includes their result for each course day. In the three years from which evaluations were available, the level of expertise of the students was comparable, as indicated by the quality of the reports and the impression of the teachers. The only change that was made to the course structure was that in the third year (2014), the time used for theoretical explanations was increased to about 20% of total course time, compared to

about 10% in the two previous years. In addition, the supervision of hands-on exercises was extended.

From the student's course evaluations, four questions were relevant in the present context:

1. "Did the course in general fulfil your expectations?"
2. "Was the balance between theory and hands-on at the microscopes good?"
3. "Did the course manual meet your needs?"
4. "Did the journal club sessions work out?"

These questions were answered by the students on a scale of 1 to 5 with 1 corresponding to "no" and 5 corresponding to "yes". The proportion of students that answered a question with "yes" (5 points) in each year is plotted in Fig. 2.1. There is no qualitative difference if instead of only the top mark all five answering options are taken into account via a weighted point system. A table with the complete data is included in Appendix A.

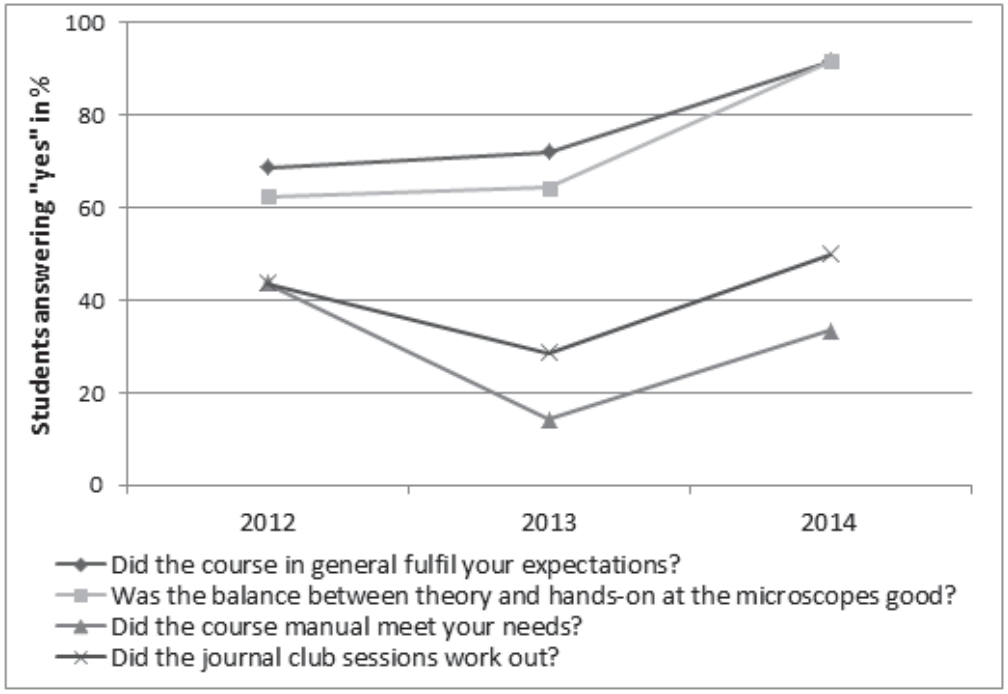

Fig. 2.1. Student evaluation of the course "Advanced Methods in Microscopy"

The overall satisfaction of the students with the course is considerably higher in 2014 compared to 2012 and 2013 (Fig. 2.1).

The coincidence of higher satisfaction with the course in general and the balance between theoretical and practical parts, while other values are rated as in previous years indicates a causal connection. This indication is supported by the fact that the time distribution between theory and practice was changed for the 2014 course. This seemed to have had a positive effect on the student's rating of the course in general.

Further evidence for the importance of the theoretical explanations is provided by several students of the 2012 and 2013 courses that made comments on the evaluation forms stating that theoretical explanations should be extended. For example, one student writes; "explanation for hands-on should be more detailed". The comments also indicate the student's general preference for supervised training instead of independent hands-on. One student writes in the evaluation of the 2012 course: "I would like to see 'the expert at work' in between theory and our own hands-on time". This could also be a factor in the good evaluation of the 2014 course, in which more supervision was provided.

The relatively low ratings of the journal club in all years indicate that this TA might not be well suited for this kind of course. Several students commented that the papers discussed in the journal club were not relevant for learning the microscopy methods that are part of the hands-on exercises.

Discussion

The results from this study provide insight into how students learn to operate microscopes and advance the debate on the effectiveness of different teaching activities.

The ILOs of courses that have a specific microscopy technique as main subject were shown not always to include the student's independent handling of microscopes. Instead, understanding of the theoretical background and the ability to choose the right technique for a certain sample are the aims that are universal in microscopy-focused courses.

Only online course descriptions were taken into account when the ILOs were analyzed. It could be the case that different or additional ILOs are presented within the course. However, only courses taught at Danish Universities were considered and Danish University teachers generally receive pedagogical training that encourages the use of precise ILOs in the course description.

Virtual microscopy has found entrance in numerous teaching situations, but mainly in Bachelor level medical training that does not aim to transfer practical microscopy skills **??**. In many cases the switch from conventional to virtual microscopes was triggered by economic considerations (Kumar et al. 2006, Krippendorf & Lough 2005). Virtual microscopy does not require laborious preparations before each teaching session and makes going through slides faster (Fjeldberg 2014, Kumar et al. 2006). Thereby, as Kumar et al. found, it helps to "minimize the adverse impact of curriculum reform on the teaching of morphology" (Kumar et al. 2006). Nevertheless, while students appreciate the accessibility of virtual microscopes, they would actually prefer at least a combination with conventional microscopy (**?**Amyanwu et al. 2012). In general, student learning is not enhanced by the use of virtual microscopy compared to traditional microscopy instructions (Krippendorf & Lough 2005, Helle et al. 2011). It can be concluded that, that virtual microscopy is a TA that can help to make teaching more efficient.

For the courses discussed here, however, the opinions of two experienced University teachers indicate that virtual microscopy would be only of limited usefulness. Especially the important ILO that students should be able to compare different methods to identify the most suited for a given sample cannot be fulfilled. This is supported by observations that students lack the concept and appreciation of the sources of tissues and images when only using virtual microscopes (Harris et al. 2001).

However, also in the present context, virtual microscopy might facilitate the realization of some ILOs when complementing hands-on focused TAs. For example, the student's understanding of theoretical background of certain techniques might benefit from virtual microscope exercises that they can complete independently at home.

With regard to the value of other TAs, information is provided through the student evaluations of a microscopy-focused course in consecutive years as presented here. The analysis is based on course evaluation sheets, which provide less information than a tailored questionnaire would. However, the high answering rate, here between 74% and 80% ensures credibility. Such answering rates would be difficult to achieve with separate questionnaires. Moreover, evaluation sheets were completed right after the courses were held, when the students still remember all details of the course. In addition, evaluations were accessible for consecutive years, which was critical for this study.

The results show that even in hands-on focused courses, students put strong emphasis on a thorough theoretical background and getting to know the different techniques. Extended theoretical instructions led to significantly better evaluation of the course in general, demonstrating its importance for achieving the course ILOs. Other TAs that help the students in their learning are expert demonstrations and extensive supervision when handling the microscopes themselves. Journal clubs, however, do not seem to be a suitable TA, generally receiving low scores in the course evaluations. The missing relevance, which is highlighted in student comments, might be partly connected to the journal club implementation, which lets students choose a paper themselves. An option could be to connect paper discussions with case-based learning. With its direct connection of research questions and hands-on exercises it can provide increased exposure to theoretical background and additional guidance for the hands-on part.

A Appendix

Data from student evaluation forms for the course "Advanced Methods in Microscopy". Values are given in % of the number of students that completed the evaluation form.

	No				Yes
Did the course in general fulfil your expectations?					
2012	-	-	6	25	69
2013	-	-	7	21	72
2014	-	-	-	8	92
Was the balance between theory and hands-on at the microscopes good?					
2012	-	-	19	19	62
2013	-	-	14	21	65
2014	-	-	-	8	92
Did the course manual meet your needs?					
2012	-	-	19	37	44
2013	-	-	36	50	14
2014	-	-	25	31	44
Did the journal club sessions work out?					
2012	-	6	6	44	44
2013	7	-	21	43	29
2014	-	-	17	33	50

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