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Development of an assessment scheme for laboratory exercises in pharmaceutical education at KU

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Introduction and problem formulation

”Students learn what they think they‘ll be assessed on, not what‘s in the curriculum” (Biggs and Tang, 2012). Although laboratory exercises, both in school and at universities, are a unique setting for teaching and learning and offer an environment for students to obtain central conceptual and procedural knowledge and skills related to experimental aspects of science, students‘ performance during the lab is often not adequately assessed, e.g., often only through conventional paper-and-pencil tests (as reviewed in Lunetta, Hofstein, and Clough, 2007 and Hofstein and Lunetta, 2004). Therefore, students often perceive the laboratory as not particularly important for their learning (Hofstein and Lunetta, 2004 and literature cited herein). This project had the goal to develop and design a system for the assessment of students‘performance in laboratory exercises in pharmaceutical education at the bachelor level. The course in focus is “Evaluation of Pharmaceutical Substances” (Kvalitetsvurdering af farmaceutiske råvarer, SFABIF107U). This course is newly developed in the course of the study reform Farma2020 and will start end of January 2016. In the old form of the course the only assessment, where students got a grade on, was a written exam at the end of the course. The practical exercises in the laboratory were assessed only with “passed/ not passed”, but had no influence on the final grade. In order to pass the practical exercises, students‘ measurement results had on average to be of a certain quality (accuracy and precision $\leq$ 0.8%) and laboratory journals, experimental protocols, and reports had to be of satisfying quality. In general, “passed/ not passed” was not bound to standardized and unified criteria and the meaning of satisfying quality was not further specified and rather dependent on the teacher. In my opinion, this system has the following shortcomings:

- A low motivation especially of the good students to put extra effort into the practical exercises in order to obtain higher-than-average results. Students see the practical part of the course as not particularly relevant, since it is not part of the final grade
- Skills related to laboratory work (planning and conducting of experiments, measurement and observation, the proper management of a laboratory journal, etc.) are largely neglected in the assessment (written exam). The assessment form is not aligned with the teaching goals of the practical part of the course.
- A standardized and objective measure of how students perform in the laboratory according to clearly stated criteria is missing. The judgement as “passed/ not passed” is rather subjective (i.e., depending on the teacher) and hard to grasp for the students. Identifying strengths and weaknesses of students and giving formative feedback to students is hampered.

These shortcomings got obvious during the course last year. Students partly entered the laboratory being badly prepared. Or students with excellent measurement results got disappointed and demotivated because they didn’t get awarded for their effort. Similar problems associated with laboratory exercises and (lack of) assessment have been reported previously in literature [3, 4]. The objectives of my pedagogical project were therefore to develop and implement an assessment system for the practical exercises of the new course. Demands set on the assessment form were the following: 1) Assessment of all phases of a laboratory activity (these are after V. N. Lunetta and Tamir, 1979 I. planning and design, II. performance, III. analysis and interpretation, IV. application, see Table 27.1), 2) A clear alignment of assessment methods to ILOs of the course, 3) assessment according to clearly stated, standardized, and transparent criteria, 4) a scaled grading, which correlates with the quality of students work. These goals are planned to be realized through assessment of student laboratory journals, experimental protocols, measurement results, and reports. Since the course, where the assessment system will be applied, starts after the university pedagogy course, the following project description focuses on how I developed the assessment system and which considerations I made in choosing assessment methods and grading schemes.

Course description

An outline of the course and of the laboratory exercises are shown in Figure 27.1. The laboratory exercises include preparation and reflection of the experiments in the classroom ("klassetimer") before and after the actual laboratory work, planning and preparation of the experiment in form of a written protocol, conduction of the experiment in the laboratory, as well as writing reports. The practical part is structured into four modules, each consisting of three different experiments. These modules are followed by project work, where students independently plan and conduct the analytical verification of a pharmaceutical compound followed by writing a report. In contrast to Module 1 to 4 the project also includes peer-review of project protocols by the students. The capacity of the course is up to 240 students, which are supervised by up to eight teacher. Due to the high number of participants students work together in groups of three.

Choice of assessment methods

"Assessment is an integral part of the teaching and learning process since the main goal of education is to produce or facilitate change in learners" (Butler, McColskey, and O'Sullivan, 2005, p.21). In order to be able to measure change in student skills it is indispensable to carefully choose appropriate assessment methods. In accordance with Butler et al. (Butler et al., 2005) the following steps were followed in order to develop a meaningful assessment system: 1) Identifying intended learning outcomes (ILOs) of our course. Only if we clearly define what competencies students are supposed to obtain can we choose and design assessment forms, which can accurately test the achievement of these ILOs. 2) Choosing assessment forms, which match the ILOs of the course. 3) Choosing grading schemes, which can communicate students‘ performance and change/ improvement in a clear and understandable manner (Butler et al., 2005). Butler et al. (Butler et al., 2005) gives a detailed overview over assessment methods. Traditional assessment methods, which (in general) assess basic factual knowledge, are for example multiple choice questions, e.g., in form of quizzes and paper-and-pencil tests. Methods, which go beyond the testing of just basic facts and skills and which can assess students‘ performance and their higher-order cognitive skills and deeper understanding in a science inquiry setting, are the following performance-based assessment methods: Observing students (Informal and structured observations), soliciting information from students (interviews, self-assessment questionnaires), evaluating students work (open-ended questions, performance tasks, journals, exhibitions and projects, portfolios) (Butler et al., 2005).

Together with the course responsible and with my technical supervisor of the university pedagogy course (UP) I discussed different assessment forms. Due to time, man power, and economic constraints not all of the above mentioned assessment methods can be applied in our course. For example methods, which require the observation of each student individually over an extended period of time, are difficult to realize in our course. These methods include practical performances, which are an excellent tool to assess students‘ procedural understanding and manipulative skills in comparison to paper-and-pencil tests [4, 6, 7]. Students should not be “sampled” only once, but continuously in order to get an impression of a student‘s learning progress (Ganiel and Hofstein, 1982). This is quite resource and time intense and not practical in our course with a total number of up to 240 students and a limited number of teachers. Before a direct assessment of practical skills in the laboratory can be introduced in our course a pilot study would have to be performed in order to test the time and resources such an assessment would take. For now, measurement results (accuracy and precision) will be used to assess students‘ practical performance in the laboratory. Experiences from previous courses show that the results correlate very well with students‘ practical skills. If students choose for example the wrong pipette or read an instrument the wrong way this will be reflected through a bad accuracy and precision. Proper maintenance of a laboratory journal is an important ILO in our course, since it is an important documentation of experimental work and is for example used as a legal document in industry (Wallert and Provost, 2014). Through using it as an assessment method students appreciation of its value can be increased (Wallert and Provost, 2014). The journal will therefore be an important part of our assessment system. Further assessment methods available in our course are written reports, where students evaluate and discuss their results, as well as protocols, where students prepare their experimental work of the project (see Figure 27.1). In addition, students basic knowledge will be tested with online quizzes (multiple choice questions) before they enter the laboratory and after each laboratory session in Modul 1 to 4.

In order to be meaningful a laboratory exercise should include all of the phases of a laboratory activity (see Table 27.1) and all of them should also be assessed (Ganiel and Hofstein, 1982). Each of the phases features individual skills, which are related to the processes of science inquiry (V. N. Lunetta and Tamir, 1979). In the practical exercises of our course all of the four phases are present (see Figure 27.1) and most of the skills listed in Table 27.1 are required. In a pre-test I checked which of the chosen assessment methods (quizzes, laboratory journals, protocols, reports) can assess which skills of the four laboratory phases. As can be seen in Table 27.1 all of the phases and associated skills can be assessed.

The next step was the alignment of the assessment methods to the ILOs of our course. ILOs comprise for example conceptual and procedural understanding of the applied analytical methods, practical skills, e.g., the handling of experimental equipment, IT skills and theoretical skills like the use of statistical methods during data analysis. As an example, ILOs of the course as a whole and of Modul 1 are lisetd in Table 27.2. Since the developed assessment system shall consider all phases of a laboratory activity I tried to assign each ILO to the laboratory phase, where it is going to be promoted (see Table 27.2). After this I assigned assessment methods, which in my opinion are suitable to measure progress of students in achieving the ILOs. As can be seen in Table 27.2 all of the four phases of a laboratory activity are needed to realize the ILOs (see also Figure 27.1). Each of the desired ILOs and phases can (in principal) be assessed with one or several of the four assessment forms mentioned above. The only exception is the assessment of the peer-review process during the project, where students give feedback to each other on their project protocols. This would require individual observation of the students and is not feasible as argued above. Although active participation in the peer-review process is one criterion to pass the project this will not be assessed explicitly. A solution for this has still to be found.

Choice of assessment criteria

One objective of this project was to assess laboratory exercises in an objective and precise way, i.e., different teacher would get a similar result of their assessments. Ganiel and Hofstein showed in their study that objectivity and precision of the assessment of students‘work in the laboratory can be increased if the assessment is performed according to a list of well-defined criteria (Ganiel and Hofstein, 1982). Furthermore, only if the assessment criteria are formulated in a clear way will students understand the expectations teachers set on them and achieve the desired ILOs more easily (Butler et al., 2005). A requirement for this is that the assessment criteria match the ILOs.

For the assessment methods laboratory journal and reports I formulated therefore criteria, which match the corresponding ILOs listed in Table 27.2. Here, published lists with assessment criteria served as a starting point [4, 5, 8]. The final criteria are shown in Table 27.4 and 27.5. Assessment criteria for the laboratory journal are divided into the categories basic form, planning of an analytical determination, experimental observations and data documentation, and calculation of results. The latter three assess tasks related to phases I, II, and III of a laboratory activity, respectively. Criteria adressing the basic requirements for maintenance of a laboratory journal and data documentation are in accordance with the Procedure for Work Documentation at PharmaSchool (Faculty of Heatlh Sciences, University of Copenhagen). Besides criteria related to the basic form of the journal I included criteria, which test practical skills of the students like doing and documenting observations during the course of an experiment. One of the ILOs of particularly the project work is that students are able to plan and design analytical determinations independently, i.e., they have to choose analytical procedures and have to plan the measurement and observation. Here, higher-order cognitive skills and deeper understanding of analytical principles behind the experiment are required. These skills are specifically assessed through the journal and protocol with criteria listed under "planning of an analytical determination". Criteria chosen for the report assessment are shown in Table 27.5. As for the journal assessment the criteria are divided into several categories like data evaluation and calculations and data interpretation. These criteria correspond to important ILOs like being able to calculate the uncertainty of an analytical procedure or the use of IT and statistical methods for data analysis. Assessed skills of the students range from practical skills, e.g., the correct use of Excell, to deeper understanding of analytical principles, like the discussion of sources for a high measurement uncertainty. These tasks belong to phase III (Data analysis and interpretation) of an laboratory activity. Phase IV (Application) is assessed in the report through study questions, where students have for example to predict results by applying the analytical method to a new situation. Last but not least, students‘practical performance in the lab gets indirectly assessed through accuracy and precision of the measurement results obtained during modul 1 to 4 and the project work. The corresponding assessment scheme is shown in Table 27.4. For both modul 1 – 4 and the project work the same assessment forms will be used.

Choice of grading forms

Students‘ answers to the online quizzes will be evaluated as “passed/ not passed”. Only if students pass the quiz are they allowed to enter the laboratory. For grading the above mentioned criteria belonging to laboratory journal and report I chose a system between a check list and a rubric. A checklist can be used in assessing student actions and behaviors, where a complex response is not expected (Butler et al., 2005), here for example if the laboratory journal contains certain entries or not. Rubrics on the other hand define different levels of proficiency in performing a certain task and are suitable for long and complex student responses Rubrics have the advantage that they define high-quality work and can aid students in achieving it (Butler et al., 2005). Where applicable I formulated criteria in a way that they reflect what is expected to be performance of high quality (see Table 27.3 and 5). Each criterion can be assessed with “yes”, “partly”, or “not” and assigned to a percentage score of 100, 50 and 0%, depending on if the criterion is entirely, partly or not at all fulfilled, respectively. Scores for the individual criteria within one category are averaged, weighted, and the average score of all categories is calculated. Since the categories and related ILOs possess different importance in our course, I inserted the option to put different weight on the individual categories. Also the measurement results are transformed into a percentage score (0, 25, 50, 100%) depending on in which interval the accuracy and precision of the performed measurements lies. In a final step percentage scores will be translated into grades according to the 7-trin scale. In order to pass an assessement the percentage score (and the associated grade) has to be above a certain threshold. How to best weigh the different categories and where to set the thresholds for passing the individual parts of the practical course will be discussed together with the teacher participating in the course.

Turning the developed assessment system into reality

It is planned that student laboratory journals are assessed together with the reports after each laboratory session of modul 1 to 4 and of the project. For this students are asked to add a copy of their laboratory journal into their report. This has the advantage that the teacher has sufficient time to properly read through the journal, but the disadvantage that it cannot be controlled if students really took their notes while conducting the experiment. But if time allows the journal will also be assessed directly during the lab exercises through scheduled and random observation events as described in (Wallert and Provost, 2014). Measurement results are recorded and assessed after each exercise.

In the classroom session used for preparation before the first laboratory exercise (Modul 1) the assessment criteria are going to be presented to the students. The goal is that students understand upfront what they will be assessed on. This will support that students work according to the teachers expectations and achieve the ILOs more easily (Butler et al., 2005). Furthermore, it is planned that the complexity of the assessment increases gradually during the practical part of the course. The number of categories assessed within the laboratory journal increases with each modul as shown in Table 27.4. This ensures that students can develop and improve a limited number of skills per modul before moving on to a more complex modul. This procedure was adapted from a notebook grading sequence developed by Wallert and Provost (Wallert and Provost, 2014).

The assessment and grading done in Modul 1 – 4 serves as an interim assessment. Only the grades obtained during the project work will be included in the final assessment of the course. This gives the students the chance to develop and improve their skills before they obtain a final grade on their performance. Students are assessed continuously, which assures that change and improvement of student skills are monitored and can be communicated to the students. This will contribute to the students conception, that improvement and change is a desired learning process in our course (Butler et al., 2005).

Anticipated effects of the developed assessment system

Through the introduction of an assessment of students‘ performance during laboratory exercises we hope that students value the laboratory exercises as an important and relevant part of their education. This has hopefully the effect that students prepare themselves better for the laboratory exercises. The developed assessment system assesses students‘ performance during all phases of a laboratory activity according to clearly stated and categorized criteria. This provides the students with a clear guideline on what they are assessed on and ensures that they understand what is expected from them. Furthermore, this helps the teacher to pinpoint strengths and weaknesses of a student in the laboratory and to give detailed formative feedback on specific skills, which can be improved. The use of standardized criteria will in addition enhance the objectivity and precision of the assessment process. A particular focus during this project was set on a clear alignment of assessment criteria to ILOs of the course. One expectation is that ILOs are achieved more effectively by the students. Since the grading is scaled (percentage scale and 7-trin scale) the assessment correlates with quality of a students‘ performance. This will motivate particularly the ambitious students to produce work of high quality. All in all I expect that the developed assessment system contributes to a higher learning yield through a more effective achievement of the ILOs of our course. I hope that the implementation of the assessment system will not demand more time from the teacher, but on the contrary facilitate and accelerate report and journal correction.

Perspectives

My technical supervisor of the UP suggested I should check on the realization of the anticipated effects during the new course. This I plan to do, e.g., through questionnaires distributed to the students and teachers during the course and/ or after the course. Depending on the experiences during the course criteria and thresholds for passing the exercises will be adjusted. In the future I would like to implement a direct assessment of students‘ pratical skills through direct observation in the laboratory. A practical exam developed by Chen et al. serves here as a good basis (Chen, Graesser, and Sah, 2015).

References

Biggs, J. & Tang, C. (2012). Aligning the curriculum to promote learning. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 198–199). Boston, MA: Springer US.

Butler, S. M., McColskey, W., & O’Sullivan, R. (2005). How to assess student performance in science: going beyond multiple-choice tests. *SERVE Center for Continuous Improvement at UNCG*.

Chen, X., Graesser, D., & Sah, M. (2015). Improving consistency in large laboratory courses: a design for a standardized practical exam. *Advances in physiology education*, *39*(2), 102–107.

Ganiel, U. & Hofstein, A. (1982). Objective and continuous assessment of student performance in the physics laboratory. *Science Education*, *66*(4), 581–591.

Hofstein, A. & Lunetta, V. N. (2004). The laboratory in science education: foundations for the twenty-first century. *Science education*, *88*(1), 28–54.

Lunetta, V. N., Hofstein, A., & Clough, M. P. (2007). Learning and teaching in the school science laboratory: an analysis of research, theory, and practice. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 393–441). New Jersey: Lawrence Erlbaum Associates.

V. N. Lunetta, N. V. & Tamir, P. (1979). Matching lab activities with teaching goals. *Science Teacher*, *46*(5), 22–24.

Wallert, M. A. & Provost, J. J. (2014). Integrating standard operating procedures and industry notebook standards to evaluate students in laboratory courses. *Biochemistry and Molecular Biology Education*, *42*(1), 41–49.

A Appendices

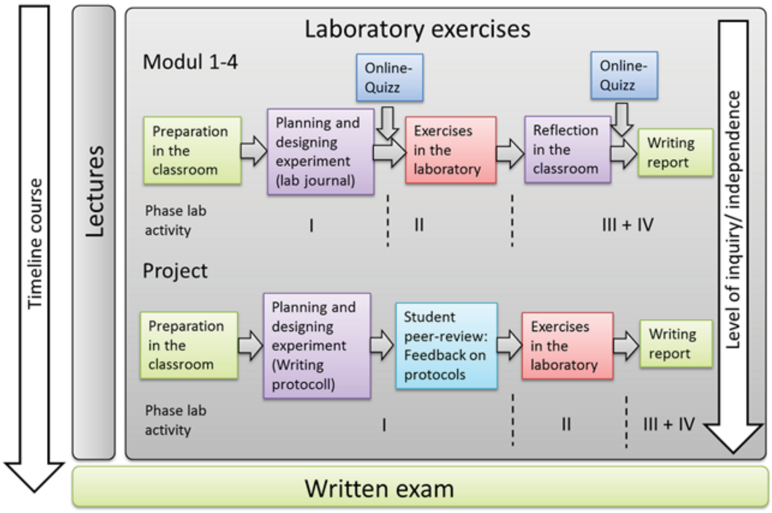

Fig. 27.1: Outline of the course “Evaluation of Pharmaceutical Substances” (Kvalitetsvurdering af farmaceutiske råvarer, SFABIF107U), where the developed assessment system for students‘performance in the laboratory will be implemented. Shown are the individual parts of the laboratory exercises of modul 1 to 4 and of the project work. Numbers I – IV represent the phases of the laboratory activities according to V. N. Lunetta and Tamir, 1979.

Table 27.1: Phases of a laboratory activity and associated skills adapted from V. N. Lunetta and Tamir, 1979. In addition assessment methods of our course, which are suitable to assess the individual skills, are listed (Q: Quizz, J: Laboratory journal, P: Project protocol, M: Measurement results, R: Report, n.r. depicts skills, which are not required in our course).

Lab phase	**Skill**	**Assessment form**
I. Planning and design	Articulating questions	n.r.
	Predicting results	Q
	Formulating hypothesis to be tested	n.r.
	Designing experimental procedures and observations	J, P
II. Performance	Conducting an investigation (measurement + observation)	M, J
	Manipulating materials and equipment	M
	Making decisions about investigative techinques	J, P
	Making, organizing, and recording observations	J
	Performing numeric calculations	J, R
III. Analysis and interpretation	Processing data (transforming and graphing data)	R
	Determining qualitative and quantitative relationships	Q, R
	Explaining relationships	R
	Developing findings	R
	Discussing the accuracy and limitations of data and procedures	R
	Formulating new questions based on results	n.r.
IV. Application	Making predictions about new situations	Q, R
	Formulating hypothesis on the basis of investigative results	n.r.
	Applying lab techniques to new experimental situations	Q, R

Table 27.2: Compilation of intended learning outcomes (ILOs) of the whole course and of the practical part of the course “Evaluation of Pharmaceutical Substances” (Kvalitetsvurdering af farmaceutiske råvarer, SFABIF107U), the corresponding phase of laboratory activity (PLA, according to V. N. Lunetta and Tamir, 1979), and assessment forms matching the respective ILOs. ILOs are taken from the course description and are described in Danish. As an example only ILOs of the whole course and of Modul 1 are shown.

Part of the course	**ILO category**	**ILO description**	**PLA[a]**	**Assessment form[b]**
Whole course	Knowledge	Opnå forståelse for/redegøre for lægemiddelstoffers proteolytiske egenskabers betydning for kvantitativ bestemmelse. Omfatter pH beregninger, beregning af titreringskurve, syrestyrkens indflydelse på titreringskurvensforløb, opløsningsmidlets indflydelse på syrestyrken.	III, IV	Q, R
		Opnå forståelse for/redegøre for kvantitative ikke chromatografiske analytiske principper; titrimetri (ligevægtsbetragtninger i forbindelse med analytisk kemiske problemstillinger), spektofotometri (UV, IR og fluorescens), vandbestemmelse, elementaranalyse. Herunder redegørelse for principper og anvendelsesområde.	I, III, IV	Q, J, P, R
	Skill	Opnå Fortrolighed med at anvende den Europæiske farmakopé til udarbejdelse af analyseforskrifter baseret på Ph. Eur. standarder og generelle krav til analytiske kemisk arbejde (præcision, afvejning, korrekt brug af glasudstyr).	I, II	Q, J, P, M
		Kan anvende statistik til vurdering af de anvendte metoders validitet og påliden af opnåede resultater (gennemsnit, standardafvigelse, usikkerhedsberegninger, potentielle fejlkilder, præcision, nøjagtighed, lineær regression af standardkurver herunder beregning af usikkerheden på standardkurvens skæring of hældning og beregning af usikkerheden på resultatet ved brug af standardkurven, simple statiske beregninger til vurdering af kvantitative resultater: t-test og F-test)	III	J, P
		Kan anvende IT i faglig kontekst til databehandling (Herunder brug af Excel til at beregne og afbilde trireringskurver og standardkurver samt bruge excels funktioner til beregning af standardafvigelser og gennemsnit, R og R2 ved lineær regression), til tekstbehandling (ved udarbejdelse af rapporter og protokoller) og til opslag i Ph. Eur. Online	III	J, P
	Competence	**Være i stand til selv at kunne vurdere simple analytiske problemstillinger samt udarbejde analyseforskrifter herfor**	I, II, III	J, P, M, R
		Føring af laboratoriejournal på en sådan måde, at denne til enhver tid kan tjene som dokumentation for udført arbejde.	II	J
Practical exercises				
Modul - 1	**Theoretical skills**	**At kunne anvende enheder**	III	J, R
		At kunne vurdere og angive antal betydende cifre for beregnede resultater	II, III	J, R
		At forstå koncentrationsangivelserne molaritet, molalitet, % w/w, % v/v, % w/v, ppm og ppb herunder omregning mellem disse	II, III	J, R
		At kunne skelne mellem den formelle koncentration og den aktuelle koncentration af en analyt.	III	R
		At kunne udføre støkiometriske beregninger baseret på opstillede reaktionsligninger	I, II, III	J, P, R
		At kunne vurdere et analyseresultat ved angivelse og diskussion af præcision og nøjagtighed	II, III	J, R
		At kunne beregne og vurdere teoretisk absolut og relativ usikkerhed for analyseresultater	III	R
		At forstå betydningen af absolut og relativ usikkerhed	III	R
	Practical skills	At kunne afveje korrekt	II	M
		At kunne udtage og afmåle volumina korrekt	II	M
		At kunne vælge det rigtige udstyr til udtagelse af volumen og masse	I, II	Q, J, P, M
		At kunne vurdere det anvendte udstyrs validitet	II	M
		At kunne udføre laboratoriejournal efter de for kursets gældende regler	II	J
	Statistics	At kunne beregne gennemsnit, standardafvigelse og relativ standardafvigelse af opnåede bestemmelser og anvende F-test herunder fortolkning af testens resultat.	III	R

a) Phase of laboratory activity after [5]: I. Planning and design, II. Performance, III. Analysis and Interpretation, IV. Application
b) Assessment methods: Q: Quizz, J: Laboratory journal, P: Project protocol, M, Measurement results, R: Report

Table 27.3: Assessment scheme for laboratory journals and protocols

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Vurdering laboratorie journalier**											
2	**Info**											
3	Navn studerende/ gruppe		Skabsnummer			Datum korrektur						
4	**Kriterie**		**Kriterie opfyldt**	**Score**			**Kommentar**	**Hvornår vurderet**				
5				Individuelt	Kategori	Weighting		Modul 1	Modul 2	Modul 3	Modul 4	Projekt
6	**Grundlæggende form**	Sort/blå kuglepen brugt	ja	100%	100%	1						
7		Indholdsfortegnelsen udfyldt, journalens sider dateret, nummeret, og signeret	ja	100%								
8		Titel og formål af et eksperiment præsent incl. reference til protokol (for eksempel Ph.EUR.)	ja	100%								
9		Registreringer kronologisk opført. Hvis fortsættelse af et eksperiment, reference til dette incl. sidenummer	ja	100%								
10		Ubrugte sider, dele af sider og forkerte data streget med en enkel streg. Sider må ikke rives ud. Sletninger med datum, initialer, og begrundelse, hvorfor streget.	ja	100%								
11		Alle resultater godkendt	ja	100%								
12	**Eksperimentelt forløb, observationer, og data dokumentation**	Alle kemikalier (incl. batchnummer og producent), udstyr og instrumenter fuldstændigt opført, anvendte instrumentenmetode noteret	ja	100%	100%	1						
13		Alle eksperimentelle skridt kronologisk opført incl. observationer, beregninger og resultater	ja	100%								
14		Observationer fokuserer på relevante parameter og er beskrevet detaljeret og på en forståeligt måde, afvigelser fra protokollen noteret	ja	100%								
15		Data dokumentation fuldstændig. Alle relevante data (aflæsninger, afmålinger, afvejninger, osv.) opført på en klar og vel organiseret måde, Vejestrimmel clipset ind. Sted, hvor elektroniske filer er gemt, noteret	ja	100%								
16	**Beregning resultater**	Beregningerne (koncentration/ indhold, gennemsnit, præcision, nøjagtighed, etc.) fuldstændig og korrekt (først generelle formler, efterfølgende værdier indsat)	ja	100%	100%	1						
17		Alle værdier med rigtige enheder	ja	100%								
18		Alle værdier med rigtige antal betydende cifre, koncentrationer afrundet til 4 decimaler, nøjagtighed og præcision afrundet til 1 decimal	ja	100%								
19		Endegyldige resultater understreget to gange	ja	100%								
20	**Planlægning af en analytisk bestemmelse, Forsøgsprotokol**	Teori/princip bag eksperimentet forstået (fuldstændig og korrekt beskrivelse af eksperimentets formål/ af analysemetoderne og af de kemiske principper bag disse/ af kemikaliernes funktion. Valg af analysemetoderne kan begrundes. Reaktionsligningerne fuldstændig opført)	ja	100%	100%	1						
21		Udarbedelse af analyseforskriften forståelig, fuldstændig og korrekt (Rigtig valg af udstyr og kemikalier, alle eksperimentelle trin detaljeret opført, valg af målte parameter og antal replikater korrekt). Forskrift kan direkt anvendes i laboratoriet. Forskrift er in overenstemmelse med Farmakopeens krav.	ja	100%								
22		Beregning af stofmængde, der tages i arbejde, og det forventede ækvivalensvolumen fuldstændig og korrekt	ja	100%								
23		Hensyntagen til sikkerhedsforanstaltninger	ja	100%								
24	**Helhedsindtryk**	Journalen er vel organiseret og ryddelig, alle nødvendige informationer præsente og opført på en klar måde (Journalen gør anden person i stand til at eftergøre eksperimentet)	ja	100%	100%	1						
25		Den studerende viser overbevisende kendskab til analytiske principper og deres anvendelsesområde	ja	100%								
26	**Total score**				100%	bestået						
27	**Score**	ja	100%	alle kriterie opfyldt								
28		kun delvis	50%	kriterie kun delvis opfyldt								
29		nej	0%	kriterie ikke opfyldt								
30	**Beståelseskriterium**	Bestået	Total ≥	85%								
31		Ikke bestået	Total <	85%								

Table 27.4: Assessment scheme for measurement results

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Bedømmelse resultater															
2	Gruppe			Skabsnummer		Stud. værdi								Bedømmelse		
3	Modul #	Eksperiment	Oplæsning #	Lab. værdi	Enhed	1	2	3	Gennemsnit	Præcision	Nøjagtighed	Godkendt		Præcision	Nøjagtighed	Bedømmelse
4	1	A	1	1.0000	M	1.0010	1.0005	0.9999	1.0005	0.06	0.0			100%	100%	
5		B	2	1.0000	M	1.0000	1.0015	0.9992	1.0002	0.80	0.0			100%	100%	
6		C	3	1.0000	M	0.9919	1.0005	0.9956	0.996	0.43	0.4			100%	100%	
7	2	A	1	1.0000	M	1.1501	1.0005	0.9999	1.0502	8.24	5.0			0%	25%	
8		B	2	1.0000	M	1.0000	1.0015	0.9992	1.0002	0.80	0.0			100%	100%	
9		C	3	1.0000	M	0.9919	1.0005	0.9956	0.996	0.43	0.4			100%	100%	
10	3	A	1	1.0000	M	1.1501	1.0005	0.9999	1.0502	8.24	5.0			0%	25%	
11		B	2	1.0000	M	1.0000	1.0015	0.9992	1.0002	0.80	0.0			100%	100%	
12		C	3	1.0000	M	0.9919	1.0005	0.9956	0.996	0.43	0.4			100%	100%	
13	4	A	1	1.0000	M	1.1501	1.0005	0.9999	1.0502	8.24	5.0			0%	25%	
14		B	2	1.0000	M	1.0000	1.0015	0.9992	1.0002	0.80	0.0			100%	100%	
15		C	3	1.0000	M	0.9919	1.0005	0.9956	0.996	0.43	0.4			100%	100%	
16	Evaluering												Modul 1	100%	100%	bestået
17													Modul 2	67%	75%	bestået
18													Modul 3	67%	75%	bestået
19													Modul 4	67%	75%	bestået
20													Total	75%	81%	Ikke bestået
21											Bedømmelse nøjagtighed og præcision					
22											Interval	Lavere græn	Bedømmelse			
23																
24											[0.0%; 0.8%]	0.0	100%			
25											]0.8%; 2.0%]	0.9	50%			
26											]2.0%; 5.0%]	2.1	25%			
27											]5.0%; ∞[	5.1	0%			
28																
29											Beståelseskriteria til hver enkelte modul				Max antal 0 %	Max antal 25 %
30											Bestået	Præcision og nøjagtighed ≥		60%	1	2
31											Ikke bestået					
32											Beståelseskriteria til modul 1-4 sammen					
33											Bestået	Præcision og nøjagtighed ≥		60%	1	2
34											Ikke bestået					

Table 27.5: Assessment scheme for reports

	A	B	C	D	E	F	G
1							
2	**Vurdering rapport**						
3	**Info**						
4	Navn studerende/ gruppe		Skabsnummer			Datum	
5	Modul #		Afleveringsfrist				
6	Øvelse #		Afleveringsdato				
7	**Kriterie**		**Kriterie opfyldt**	**Score**			**Kommentar**
8				Individuelt	Kategori	Weighting	
9	**Forpligtende kriterie**	Afleveringsfrist overholdet	ja	100%			
10		Rapport fuldstændig: Alle felter udfyldt, alle beregninger udført, alle dokumenter præsente (regnearker, grafer, kopi labjournal))	ja	100%			
11		Brug af IT (Reaktionsligninger skrevet med ligningseditor, Beregninger udført i Excell)	ja	100%			
12	**Reaktionsligninger**	Reaktionsligninger rigtig og fuldstændig (alle trin, pKa værdier, i ionform eller stofform)	partly	50%	50%	1	
13	**Data evaluering og beregninger**	Generelle formler præsent og rigtig (udledning af formler fuldstændig og rigtig, symboler rigtige og klare)	ja	100%	100%	1	
14		Beregningerne (koncentration/ indhold, gennemsnit, præcision, nøjagtighed, etc.) fuldstændig og korrekt	ja	100%			
15		Enheder præsente og rigtig	ja	100%			
16		Antal betydende cifre rigtig	ja	100%			
17		Grafiske præsentationer rigtig og fuldstændig (titel, skala, beskrivelse, etc.)	ja	100%			
18	**Statistik**	Korrekt anvendelse af statistik til databehandling og vurdering af	ja	100%	100%		
19	**Usikkerhedsberegning**	Udledning af generelle formler til beregning af den absolutte og relative usikkerhed fuldstændig og korrekt	ja	100%	100%	1	
20		Beregning usikkerheder fuldstændig og rigtig (relativ og absolut usikkerhed, middelværdi af de absolute usikkerheder, usikkerhed på	ja	100%			
21	**IT færdigheder**	Beregninger i Excell er klare (Række-/kolonnensymboler, brugte Excell-formler er opført, indhold af felter er beskrevet)	ja	100%	100%	1	
22		Korrekt brug af Excell-funktioner	ja	100%			
23		Korrekt brug af Word og ligningseditor	ja	100%			
24		Korrekt brug af regneark til databehandling	ja	100%			
25	**Diskussion resultater**	Resultater uddybend diskuteret (kvalitet af resultater, mulige fejlkilde, fordele/ ulemper af analysemetoden, forslag til forbedringer). Studerende demonstrerer dybere forståelse af emnet	ja	100%	100%	1	
26	**Studiespørgsmål**	Besvaret rigtig	ja	100%	100%	1	
27		Uddybend besvaret/ diskuteret	ja	100%			
28		Studerende kan anvende eksperimentelt viden til nye problemstillinger, kan forudsige resultater	ja	100%			
29	**Helhedsindtryk**	Rapport er vel organiseret og ryddelig	ja	100%	100%	1	
30		Den studerende viser overbevisende kendskab til analytiske principper og deres anvendelsesområde, til anvendelse af statistik og IT til databehandling, og kan uddybend diskutere resultater.	ja	100%			
31	**Total score**				93%	bestået	
32	**Score**	ja	100%				
33		nej	0%				
34		partly	50%				
35	**Beståelseskriterium**	Bestået	Total ≥	85%			
36		Ikke bestået	Total <	85%			

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