ExperD: Web-based Support for Laboratory Class Workflow Design and Execution

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Abstract: The design, use, and evaluation of a web-based experiment designer, ExperD, are described. ExperD supports students in designing a research strategy for their laboratory class. Next, ExperD supports students in their actual laboratory class work by showing them which experiments they have to carry out, and what the relation is between experiments. The use of ExperD was evaluated in the 2009 and 2011 editions of a Food Chemistry course at Wageningen University in The Netherlands. The evaluations showed that students (n = 60 and 98) find ExperD helpful and that teachers see the ExperD as a valuable addition to the laboratory class. Usage logs show that students used the tool throughout the entire laboratory class. Furthermore, the ExperD proved to be a promising research tool for monitoring both student design activities as well as student actual lab work activities.

1 INTRODUCTION

Laboratory classes are an essential part of chemistry education. With respect to the work presented in this article, we focus on two challenges in laboratory class education. Firstly, skills related to designing experiments are often undertrained in laboratory classes (Bennet and O'Neale, 1998; Domin, 1999). Secondly, students can experience working memory overload in laboratory classes (Johnstone, 1997). If a problem requires the learner to have too many chunks of information in his or her working memory simultaneously, this memory becomes 'overloaded'. Working memory overload hampers both the problem solving process and learning (Kirschner 2002; Sweller et al., 1998). In practice, this will lead to less effective and less efficient laboratory classes (Johnstone, 1997). These two challenges were also recognized in the B.Sc. 'Food Chemistry' laboratory class at the Wageningen University. In the remainder of this article we first describe this laboratory class in more detail, followed by the aim and methodology of the research presented here. Next, we describe the web-based design tool ExperD and two case studies in which ExperD was evaluated. Finally, we discuss the results of this evaluation.

1.1 The B.Sc. 'Food Chemistry' Laboratory Class

The eight week morning course 'Food Chemistry' (6 ECTS credits) at Wageningen University in the Netherlands consists of four parts. In the first three weeks students attend lectures, practice the theory using digital exercises and perform self-study. The next three weeks are spent in a laboratory class. Next a self-study week is scheduled followed by an exam in the 8th week of the course. During the laboratory class students should:

- Learn to work together in small groups.
- Acquire hands-on experience with common food chemistry research methods.
- Learn to design a research strategy.

Students work in small groups of 2-3 students. Each group is given an agricultural material (e.g. barley) and investigates major chemical changes during simulated processing (e.g. beer brewing) during the 3 weeks. For example, in the case of barley, groups mimic the first steps in beer brewing on a bench scale and are asked to investigate what happens to the major carbohydrates and proteins. Groups are guided through the investigation by 15-19 assignments. They design their research strategy by relating these assignments to common food chemistry experiments. There is a many-to-many

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relationship between assignments and experiments: Assignments relate to multiple experiments and experiments relate to multiple assignments. Assignments as well as experiments can take more than one day to complete. The groups should make a time schedule of their laboratory work and distribute tasks among group members. Once a group has completed the formulation of their research strategy they have to present their set-up to a teacher. The teacher provides feedback such as pointers to inconsistencies or inefficiencies.

In general, teachers of the Food Chemistry laboratory class were not satisfied with the research strategies student groups came up with. Many groups made unclear designs, others just made a list of experiments and assignment numbers (see Figure 1).

Apple

Pressing: 18 (1 hour, -)
Enzymatic treatment
- 1 hour 19 (2 hour, 1 hour waiting time)
- 2 hour 19 (3 hour, 2 hour waiting time)

Brix: 24, 34 (45 min and 10 min, -)
Total phenolic compounds together with peanut 50 (4 hour, 2,5 hour waiting time)
Total carbohydrate + reducing sugars: 35, 37 (1,5 and 2 hour, nothing and 30 min)
Distinguish soluble polysacharides & small sugars 36 (2 hour, 1 hour waiting time)

Polyphenoloxidase substrate specifity 22 (30 min, 15 min waiting time)
Enzymatic browning 23 (30 min, -)
Apple Jam 21 (1,5 hour, -)
Stability of pectin 20 (2,5 hour, 1,45 hour waiting time)

Figure 1: Example of research strategy design made by students.

As a consequence of the unclear designs, teachers often had to spend quite some time on figuring out what students meant, and felt it was difficult to give sufficient adequate feedback. In defense of the students it can be argued that they did not receive training nor guidance in making clear research strategies. We therefore felt that there was an opportunity to improve the laboratory class by offering students support in designing research strategies.

Teachers also observed that the majority of the students were 'just carrying out a list of experiments' during the laboratory class. So most students did not know why they were carrying out a particular experiment, nor the relation of that particular experiment with the research strategy as a whole. With (Johnstone, 1997) we attribute this behavior - at least partly - to an overloading of working memory. We further hypothesize that this overloading was related to the research strategies that they had designed and in particular to the chaotic nature of the formulation of these strategies. This reinforced our belief that offering support in making a clear research strategy could improve the laboratory class.

1.2 Aim of this Research

The aim of this design oriented research was to address the opportunity described in the above section. As workflows of experiments are not an uncommon format for food chemists to present their research strategies, e.g. (Christiaens et al., 2012; De Roeck et al., 2008; Chassaigne et al., 2007), the basic idea was to provide a web based tool that would support students in designing a workflow of experiments. Teacher-student and student-student interactions could then benefit from the standardized representation of the workflow designs. Additionally, the workflow could function as a scaffold during laboratory work, as it would give students a clear view on the relation between experiments and insight in their progress. To our knowledge, such a tool for chemistry laboratory classes does not exist yet.

The following research question was leading during the research: Is it possible to design, realize and implement a web based experiment workflow design tool that

1. students find helpful?
2. teachers find valuable?
3. students really use during the laboratory class?
4. serves as a research tool for monitoring student design activities and student progress during the laboratory class?

1.3 Research Method

Design oriented research aims at the generation of knowledge by designing a new artefact (Busstra, 2008; Österle et al., 2010). This model focusses on sharing knowledge with respect to sensible goals in a well specified real university context, providing arguments why these goals make sense and demonstrating how they can be achieved in that context (Hartog et al., 2010). The goals are formulated in terms of testable design requirements, which are used to evaluate the realized and implemented artefact (Verschuren and Hartog 2005). For the design we chose the satisficing strategy, a strategy that tries "to meet criteria for adequacy, rather than identifying an optimal solution" (Jonassen, 2008) Our design requirements are listed in Table 1. From now on we will refer to the realized design by its name 'ExperD'.

The ExperD would have to be implemented in an existing educational setting. This implied that it should fit the existing infrastructure and some already available web based resources. In particular,

Table 1: ExperD design requirements. Evaluation questions use a five-point Likert scale (1 = agree, 5 = disagree) for response. Our satisficing criterion is that we consider the design requirements to be met when at least 80% of the students rate an item as 4 or 5.

Design requirement	How to determine whether the design requirement is met.
r1. According to the students ExperD should be helpful	Student questionnaire questions/statements:
a. in general	q1. "I found it useful to design a scheme." q2. "I would like to have such an ExperD in other laboratory classes."
b. in order to work efficiently	q5. "The ExperD helped our group to work efficiently."
c. by giving them the overview	q6. "The ExperD helped me to figure out what I could expect during the laboratory class." q7. "The ExperD helped me to have the overview during the laboratory class."
d. by being easy to use	q3. "The ExperD was easy to use." q4. "The ExperD was self-explanatory." q8. "It was easy to distribute tasks using the ExperD's user interface"
r2. Be really used by groups during their practical work	Usage logging: 80% of the groups should be updating their experimental workflow during the first two weeks of the laboratory class.
r3. Be appreciated by the teachers.	Teacher interviews
r4. Serve as a monitoring tool for design activities.	Teacher interviews / Usage logging

ExperD would make use of desktop computers that are present on the student laboratory benches. Moreover, ExperD should become part of the content management system Drupal™ 6, which is used by the Laboratory of Food Chemistry to deliver and manage their e-learning resources. Thirdly, the ExperD should be integrated with the web based laboratory manual developed earlier (Kolk et al., 2011).

1.4 ExperD

Taking into account the design requirements from Table 1 and a set of design and usability recommendations (Mayer, 2009), a web-based environment for the design of an experimental workflow (ExperD) was realized. The user interface of the ExperD consists of five main elements: 1) a main bar with available experiments, 2) a workflow view containing 3) one or more experiments, 4) a dialog window to edit the properties of the selected experiment (Figure 2) and 5) a time planner (Figure 6). These user interface elements can be configured depending on the characteristics of the course. In the remainder of this section ExperD's user interface elements will be discussed as they were configured for the course 'Food Chemistry'.

With ExperD, students design a research strategy in the form of a workflow of experiments. In the 'Food Chemistry' course, they do this by choosing one of the assignments from the available experiments and adding the appropriate experiments to the workflow (Figures 3 and 4). Students connect those experiments of which samples should be transferred from one experiment to the next. For example: They connect the experiment 'Get starch solution' to the experiment 'Hydrolyze starch with enzymes' because the sample obtained in the former experiment is used in the latter experiment. Next, students describe the sample in chemical/physical terms by selecting one or more properties from a list with properties (see Figure 5). For example: Does the sample contain carbohydrates, fats, proteins; is the sample solid or liquid? To support the design process, the ExperD gives feedback on the properties selected by the students. For example: the experiment 'Grind sample' does not expect a liquid sample, so if students try to connect an experiment to 'Grind sample' having a liquid sample, the ExperD gives a warning message (Figure 3). Because the feedback is based on the properties of the ingoing samples – and not on the upstream experiments providing these samples – teachers do not have to adjust the feedback of existing experiments when they add or remove experiments. Besides describing the sample properties, students can enter other data for each experiment.

They can enter for what assignments/research questions they need the experiment, what the experiment's purpose is, which group member is going to carry out the method, what the results are and when the method will be carried out. The scheduling of methods is done in a 'Gantt chart' like manner (Figure 6): Students drag and drop, stretch and shrink the experiments on a horizontal time axis to obtain a time planning. Lastly, an experiment in the ExperD can be linked (Figure 7) to a learning object in a web based laboratory manual (Kolk et al., 2011).

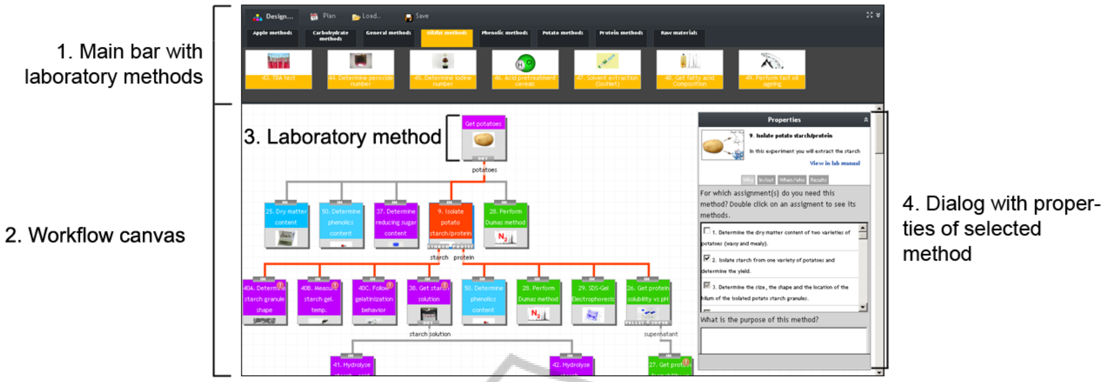

Figure 2: Overview of the ExperD's user interface. Students design their experimental workflow by selecting experiments from the Main bar (1). The experiments (3) are added to the Workflow canvas (2) and students can connect them, or change their properties using a dialog (4).

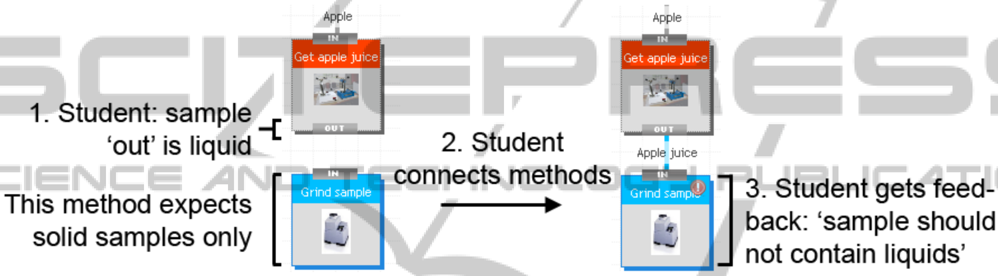

Figure 3: The ExperD's feedback system is based on the student-defined properties of the samples going from one method to another.

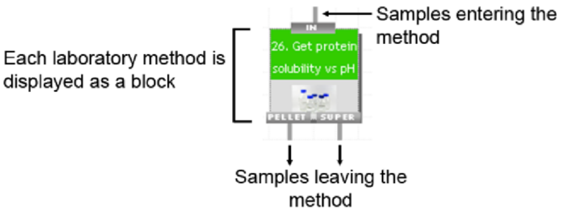

Figure 4: An experiment in the ExperD is displayed as a block with ingoing and outgoing samples. For example: the experiment 'Get protein solubility vs pH' has one ingoing sample 'In' and two outgoing samples 'Pellet' and 'Supernatant'.

1.5 Two Case Studies

The ExperD was implemented and evaluated in the 2009/2010 (further referred to as '2009') and 2011/2012 ('2011') editions of the course 'Food Chemistry'. The set-up of the laboratory class did not significantly change between these two editions. There were differences between the versions of the ExperD software used. The version of ExperD that was used in 2009 did not yet include a time planning module. This came only available in 2011. In 2009 students had to save the workflow manually a few times a day. In 2011 this workflow saving was

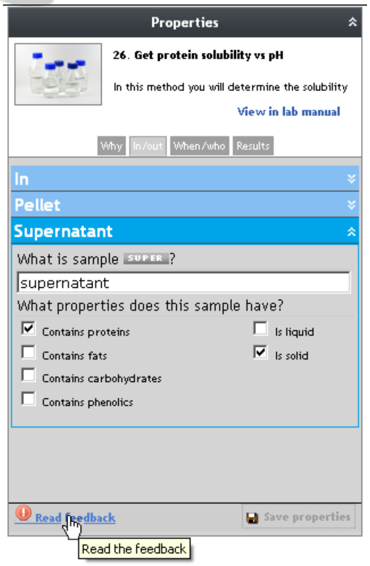

Figure 5: The properties dialog as configured in the course 'Food Chemistry'. In this dialog students can view/edit the properties of the selected experiment.

automated: any change to the workflow was instantly saved. In 2011 ExperD failed to provide feedback due to a technical problem.

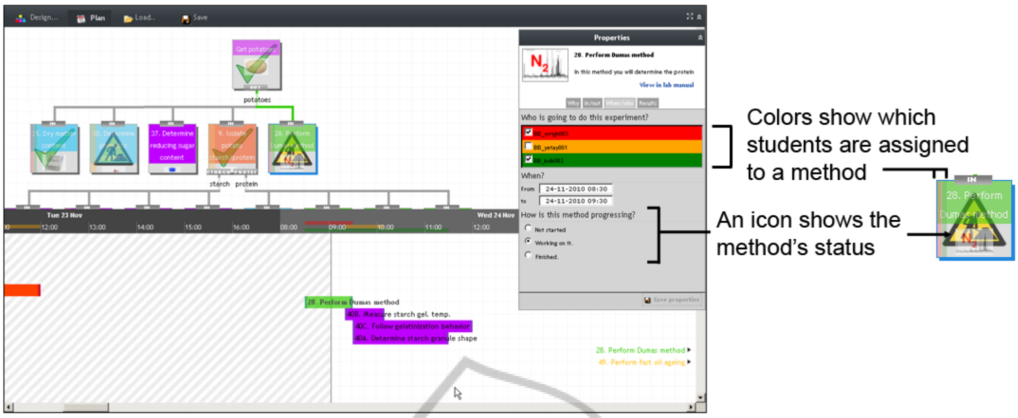

Figure 6: Overview of the time planning module with the ExperD (introduced in 2011). Each experiment is in the workflow represented by a horizontal bar in the time planning. The position and the length of this bar represent the starting time and the duration of the experiment. The shaded area in the time planner means the past, the white area the future. Each student in a group has a color (red, orange, green) and these colors are used throughout the user interface to show which method is assigned to which student(s). Icons are used to show the method's status: Whether it is 'in progress' or it has been 'finished'.

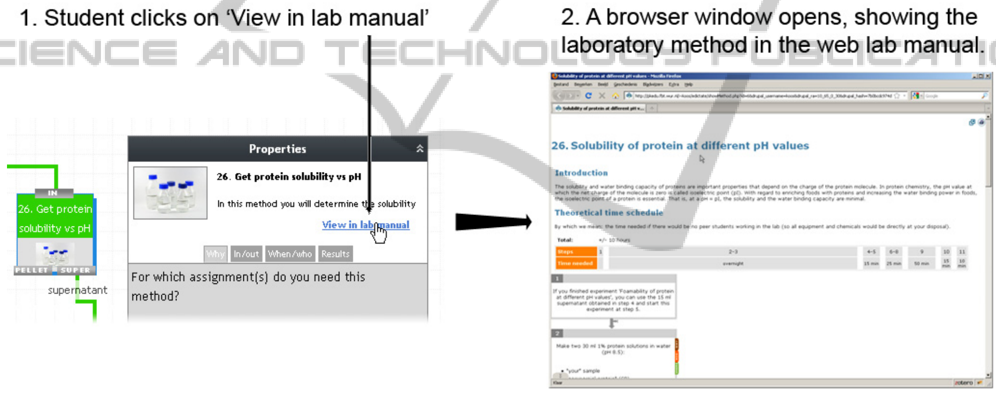

Figure 7: ExperD is linked to a web based laboratory manual. Students can view the online manual of a particular method by clicking on the 'View in lab manual' link in the properties dialog.

In both editions of the course, students designed a concept workflow on the first day of the laboratory class. The teachers then gave oral feedback on the workflows, after which students made some adjustments. Students used the workflow throughout the remainder of the laboratory class, e.g. to see what experiments they scheduled for a particular day, to enter results, to update it, etc.

In 2009 (n=60) and in 2011 (n=98) the ExperD was evaluated by the students by means of a questionnaire, which they had to fill in after the laboratory class ended. In 2009, teachers of this laboratory class (excluding those who supervised the class for the first time, n=4) were interviewed by one of the authors a few weeks later. The 2011 teachers (n=6) were asked to comment on the conclusions of the 2009 interviews.

1.6 Collected Data

The results of the questionnaire are listed in Table 2. The most important outcomes from the teacher interviews from the 2009 case study were:

t1. The teachers find the ExperD a valuable addition to the laboratory class. It especially helped teachers in discussions with students during the laboratory class, because both they and the students could easily indicate certain points in a standardized workflow. All groups did forget to include one or more experiments in their initial workflow designs.

t2. Some teachers had indications that their students had more overview during the laboratory class than in previous years. For example: They recalled several occasions where students themselves found out that they could combine the samples for certain analyses. The teachers did not recall that this occurred in previous years.

t3. Some student groups seemed to have stopped thinking about the laboratory class design after they finished designing it. When asked ‘why are you doing this experiment?’, the answer these groups gave was: ‘Because it is in the scheme’.

t4. The ExperD allows groups to make a ‘perfect’ separation of tasks. ‘Perfect’ in the sense that students did not know what experiments other group members were doing. Within groups ‘specialists’ arose, who did all analyses of a specific kind, often without knowing anything about the samples they had to analyze.

These outcomes were confirmed by the 2011 teachers of the course.

In Figure 8 the percentage of groups updating and using the ExperD are plotted against time. The method status (whether a method was ‘in progress’ or ‘finished’) was kept up to date by 90% of all groups during the laboratory class.

In Figure 9 the ExperD usage and webLM usage are plotted per group. Between groups we found substantial differences in the intensity in which the ExperD was used (Figure 9), the most active group generating 11 times as much updates as the least active group.

1.7 Discussion

In the introduction we mentioned several challenges for our laboratory class, which were operationalized in a set of design requirements (Table 1). We will discuss whether these design requirements have been met, and come up with some recommendations to improve the ExperD.

1.7.1 Requirement 1 and 2: The ExperD should be Helpful for and used by Students

Students found it useful to make a design with the ExperD on beforehand (q1 in Table 2). Surprisingly, the 2009 students seem to find it more useful to design a scheme than the 2011 students. We have no explanation for this difference, but the design requirement r1 was met in both cases. A large majority (84-86%) of the students would like to see the ExperD to be available in other laboratory classes (q2). Students also indicate that the ExperD helped them to work efficiently (q5). Although this self-reporting has some value (e.g. with regard to student motivation), ‘working efficiently’ should be further operationalized in a follow-up study to make more objective claims. A similar conclusion can be drawn for ‘the ExperD gives students the overview’ (requirement 2c): We have indications that the ExperD gives students the overview (q7, t2), but also indications that point otherwise (t4). Although the students find the tool easy to use (q3, q8), the result for q4 “The ExperD is self-explanatory” is still unsatisfactory. This could be improved by offering students an interactive tutorial before they start designing, or by giving inline hints when they use the ExperD for the first time (e.g. a textbox near the main bar: ‘Click on a method to add it to the workflow’, followed by a textbox near the added method: ‘Click on a method to see its properties’, etc.).

Table 2: Questionnaire results of the 2009 (n=60) and 2011 (n=98) case studies. For each question two result rows are shown: the upper one being the results of 2009, the lower one the results of 2011.

#	Question	Answers (%) 1=disagree, 5=agree					% 4+5
		1	2	3	4	5	
q1	I found it useful to design a scheme.	0	3	0	30	67	97
		1	5	14	49	32	81
q2	I would like to have such an ExperD in other laboratory classes.	0	2	15	37	47	84
		0	2	12	48	38	86
q3	The ExperD was easy to use.	3	3	7	53	33	86
		0	7	11	59	22	81
q4	The ExperD is self-explanatory.	2	5	25	58	11	69
		0	8	15	67	10	77
q5	The ExperD helped our group to work efficiently.	0	3	3	58	36	94
		0	3	13	58	26	84
q6	The ExperD helped me to figure out what I could expect during the laboratory class.	2	2	10	64	22	86
		0	1	10	75	14	89
q7	The ExperD helped me to have the overview during the laboratory class.	0	0	9	64	28	92
		0	1	3	49	48	97
q8	It was easy to distribute tasks using the ExperD’s user interface.	3	3	19	41	34	75
		1	2	16	59	22	81

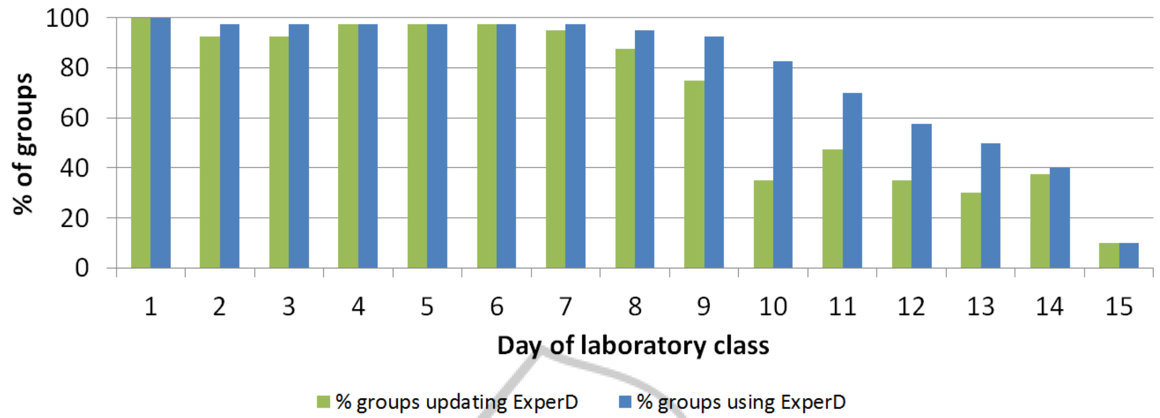

Figure 8: Percentage of groups updating and using their ExperD workflow at least once during the 2010 laboratory class. Groups making at least one change to their workflow are considered to be an 'updating' group for that day. Some groups did not update the workflow for one day, but did update it the next. Because we assume that these students did use the workflow in between (for viewing only), these groups are considered to be 'using' the ExperD on both days.

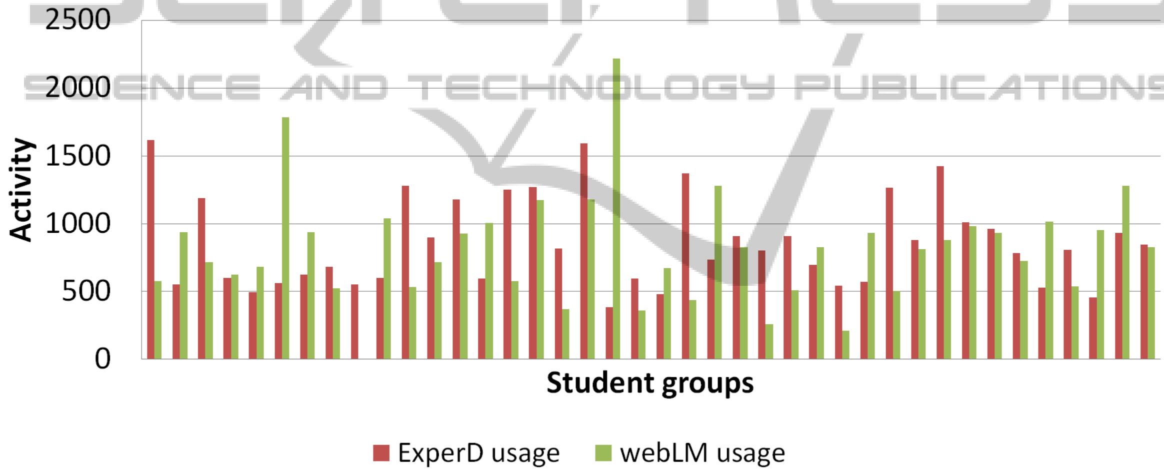

Figure 9: The ExperD and web lab manual (webLM) usages per 2011 group. To obtain the ExperD activity values, the number of laboratory methods changed in the workflow during the laboratory class was summed per group. The webLM usage was determined as described previously (Kolk et al. 2011). For one group, webLM usage data became unusable because of a problem in the logging software (the other groups were unaffected by this problem).

The majority (>80%) of the groups continued using their experimental workflow during the first 10 days of the laboratory class (Figure 8). The usage declines in the second and third weeks, most likely because laboratory class workflows did not need to be adjusted anymore and because groups finished their experiments. Earlier we expected that there would be 'computer minded' groups, which would use both the ExperD and webLM intensively, and less 'computer minded' groups, which would avoid using both tools. Our results indicate that this is not the case.

1.7.2 Requirement 3: The ExperD should be Appreciated by Teachers

In general, the teachers find ExperD a valuable addition to the laboratory class, as it helped them in their discussions with students (t1). However, teachers were somewhat unpleasantly surprised by the extent to which the ExperD enabled students within a group to work independently from each other (t5). It can be argued though, that ExperD made a 'weakness' of the laboratory class set-up apparent. Namely, that it is possible for a student group to solve the assignments and obtain a sufficient mark for the laboratory class without the student group members knowing what the others are doing.

Teachers observed that all student groups did forget to include one or more experiments (t2). Letting the ExperD check for 'childless' assignments (i.e. assignments without methods linked to them) or 'orphan' methods (i.e. methods in the workflow without assignments linked to them) could prevent these kind of mistakes in the workflows.

1.7.3 Requirement 4: The ExperD should Serve as a Monitoring Tool for Design Activities

Figure 8 and Figure 9 show possible usages of monitoring student design activities. Because each update to the workflows is saved instantly, teachers can monitor student design activities in real time from their own computer. This can help them e.g. in finding groups that are struggling to make progress during the laboratory class. Student groups have the possibility of changing the 'status' of an experiment in the workflow. For groups using this feature - 90% of all groups - a chart could be developed, in which group progress is plotted against time. This gives teachers a quick indication of how groups are performing in the laboratory class. Finally, the data generated by ExperD allows for replaying the workflow design process and reconstructing how groups progressed through the laboratory class. Analysing this process might be useful to find the problems students have with designing workflows of laboratory classes in general. It can also be used by teachers to detect difficult or unclear assignments and other bottlenecks in a specific laboratory class.

1.8 Concluding Remarks

The leading research question in this research was: Is it possible to design, realize and implement a web based experimental workflow design tool, which students find helpful, which teachers find valuable, which students really use and which can serve as a research/monitoring tool? In other words, we aimed to falsify the hypothesis that it is *not* possible to design, realize and implement such a tool. We believe that the case studies in which ExperD was used falsify this hypothesis and thus provide a proof of feasibility. ExperD is a highly-valued tool, used intensively by a large majority of the students within our laboratory class, and might be of use for both teachers and researchers. Since the 2009 evaluation, ExperD has also successfully been introduced to the laboratory classes of an interdisciplinary B.Sc. level course 'Food Related Allergies and Intolerances' and a M.Sc. level course 'Food Ingredient Functionalities'. We are currently in consultation with other chair groups at Wageningen University to investigate how to implement ExperD in their laboratory education.

REFERENCES

Bennet, S. W. & O'Neale, K., 1998. Skills development and practical work in chemistry. *University Chemistry Education*, 2(2), pp.58–63.

Busstra, M. C., 2008. *Design and evaluation of digital learning material for academic education in Human Nutrition*,

Chassaigne, H. et al., 2007. Investigation on sequential extraction of peanut allergens for subsequent analysis by ELISA and 2D gel electrophoresis. *Food Chemistry*, 105(4), pp.1671–1681.

Christiaens, S. et al., 2012. In situ pectin engineering as a tool to tailor the consistency and syneresis of carrot purée. *Food Chemistry*, 133(1), pp.146–155.

Domin, D. S., 1999. A Content Analysis of General Chemistry Laboratory Manuals for Evidence of Higher-Order Cognitive Tasks. *Journal of Chemical Education*, 76(1), p.109.

Hartog, R., Beulens, A. & Tramper, J., 2010. Faculty-based design-oriented research on digital learning materials: Defining project goals. *Global Learn Asia Pacific 2010*, 2010(1), pp.1418–1427.

Johnstone, A. H., 1997. Chemistry teaching—science or alchemy? *Journal of Chemical Education*, 74(3), pp.262–268.

Jonassen, D. H., 2008. Instructional Design as Design Problem Solving: An Iterative Process. *Educational Technology*, 48(3), pp.21–26.

Kirschner, P. A., 2002. Cognitive load theory: implications of cognitive load theory on the design of learning. *Learning and Instruction*, 12(1), pp.1–10.

Kolk, K. van der et al., 2011. Students Using a Novel Web-Based Laboratory Class Support System: A Case Study in Food Chemistry Education. *J. Chem. Educ.*, 89(1), pp.103–108.

Mayer, R. E., 2009. *Multimedia Learning* 2nd ed., Cambridge University Press.

Österle, H. et al., 2010. Memorandum on design-oriented information systems research. *European Journal of Information Systems*, 20(1), pp.7–10.

De Roeck, A. et al., 2008. Effect of high pressure/high temperature processing on cell wall pectic substances in relation to firmness of carrot tissue. *Food Chemistry*, 107(3), pp.1225–1235.

Sweller, J., van Merrienboer, J. & Paas, F., 1998. Cognitive architecture and instructional design. *Educational Psychology Review*, 10(3), pp.251–296.

Verschuren, P. & Hartog, R., 2005. Evaluation in design-oriented research. *Quality and Quantity*, 39(6), pp.733–762.