Design of an electronic performance support system for food chemistry laboratory classes

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Abstract

The design oriented research described in this thesis aims at designing an realizing an electronic performance support system for food chemistry laboratory classes (labEPSS). Four design goals related to food chemistry laboratory classes were identified. Firstly, labEPSS should avoid extraneous cognitive load caused by the instructional format of the laboratory classes. Secondly, labEPSS should let students prepare for their laboratory experiments. Thirdly, labEPSS should support the communication in the laboratory class between students and between students and supervisors. Fourthly, labEPSS should give students the freedom to plan their experiments, without supervisors losing control and without risking overbooking of equipment. To address these goals, a couple of tools were designed, realized and subsequently used and evaluated in two model food chemistry laboratory classes:

- A web-based laboratory manual, aiming to provide students with just-in-time procedural information (e.g. how an apparatus looks like, where chemicals can be found).
- A web-based experiment design tool, aiming to let students design their research strategy as a workflow beforehand and support students while carrying out this strategy in the laboratory.
- A 'web-app' for students' smartphones providing the same functionalities as the digital laboratory manual.
- A web-based equipment booking system, which is part of the web-based experiment design tool.

Based on the evaluations it can be concluded that students and supervisors appreciated the tools and that these tools are capable of reaching the design goals. Finally, an overall design of labEPSS is proposed, in which the tools offer an integrated experience. Because labEPSS is highly configurable, it can be used in many different laboratory classes throughout curricula.

List of abbreviations

BYOD	Bring Your Own Device
CL	Cognitive load design goal (Chapter 6)
CO	Communication design goal (Chapter 6)
CSS	Cascade Style Sheet, used to describe the look and formatting of a web page
DORA	Design Oriented Research Approach
ExperD	Experiment Designer
FC	Freedom and control design goal (Chapter 6)
HTML	HyperText Markup Language (markup language for web pages)
labEPSS / EPSS	(laboratory) Electronic Performance Support System
LoFC	Laboratory of Food Chemistry
MySQL	My Structured Query Language (relational database management system).
PHP	PHP: Hypertext Preprocessor (programming language for web development).
PP	Prepare design goal (Chapter 6)
webLM	Web lab manual

1. Introduction

The research described in this thesis deals with the design, realization, implementation, use, and evaluation of an electronic performance system for food chemistry laboratory education (labEPSS). This research is conducted at Laboratory of Food Chemistry (LoFC) at Wageningen University, Wageningen, The Netherlands. In this chapter the context, aims and outline of this research are sketched.

Food chemistry: research and education

Diederen (2005) compared the descriptions that Fennema, Belitz and other protagonists gave of the field of 'food chemistry'. According to Diederen (2005), the field of food chemistry deals with heterogeneous food systems consisting of many different and interacting constituents. These constituents include water, carbohydrates, lipids, proteins, peptides, amino acids, enzymes, vitamins, minerals, colorants, flavours and contaminants. Food systems undergo many changes during harvesting, processing and storage with regard to nutritional and sensory quality. Because of these characteristics, food chemistry research is also heterogeneous: Many different techniques are used to analyse the constituents playing a role in chemical reactions.

Research carried out at LoFC aims to 1) identify and understand the importance and activity/reactivity of individual constituents in foods and agricultural raw materials during industrial processing; 2) selectively modify individual food constituents with enzymes or by fermentation; 3) unravel the interactions between food constituents mutually and interactions of individual food constituents with enzymes and micro-organisms present in the gastro-intestinal tract. Agricultural raw materials, and especially processed ones, often contain many closely related molecules. It is the vision of LoFC that for a number of applications the functionality of a food or ingredient is often determined by a small subset of closely related molecules. Hence, identification and quantification of these molecules is of key importance to determine their potential impact. In order to do so, LoFC aims to maintain a high level of analytical mass spectrometry and chromatographic methodologies.

The Laboratory of Food Chemistry participates in the B.Sc. and M.Sc. programmes on 'Food Technology', 'Nutrition & Health' and 'Biotechnology' of

Wageningen University. The Laboratory supervises several regular courses; all courses except one are worth 6 ECTS credits. The courses will now be briefly discussed. The B.Sc. course 'Nutritional Aspects of Foods' deals with the relation between the consumption of specific food constituents and the prevention of diseases, e.g. cardiovascular diseases and diabetes. Furthermore, the influence of processing and consumption on the bio-functionality of food constituents is discussed. The B.Sc. course 'Food Chemistry' served as a model course for the research in this thesis and will be discussed in more detail below. During the B.Sc. course 'Food Related Allergies and Intolerances' students get an introduction to food allergies. They learn the mechanisms behind allergic reactions to food constituents, how to identify them, how to avoid them and about food labelling regulations. The B.Sc. course 'Food Properties and Function' (8 ECTS credits) combines the knowledge of different food science disciplines to study the effect of processing on food products, in relation to innovation of food products. The M.Sc. course 'Food Ingredient Functionality' also served as model course, and is discussed below. 'Advanced Food Chemistry' (M.Sc.) deals with food quality. The effects of processing and storage conditions on the chemical composition of lipids, carbohydrates and proteins are discussed in detail. Finally, during the M.Sc. course 'Enzymology for Food and Biorefinery' students learn to select the right enzyme in order to control a specific enzymatic process in the production of foods or during biorefinery processes. For this selection multiple variables have to be taken into account, e.g. pH, temperature, reaction products, the substrate matrix.

The heterogeneity of food chemistry and food chemistry research is being reflected in these courses. Furthermore, most courses combine concepts from multiple disciplines within food technology: Food immunology, food physics, food safety, nutrition and health. Typically, a food chemistry course consists of two parts: a theoretical part (lectures, tutorials and exercises) followed by a practical part, spent in the laboratory. In the laboratory class, students spend 13-36% of the time they spend on the course as a whole (contact hours and self-study hours). If the contact hours are taken in to account, these percentage are 53-67%.

Laboratory classes: objectives and instruction styles

Many objectives for laboratory class teaching have been suggested in literature. Kirschner and Meester (1988), for example, found as many as 120 different specific objectives, which they grouped in 8 general objectives (go). These are:

go1. Formulate hypotheses.
go2. Solve problems.
go3. Use knowledge and skills in unfamiliar situations.
go4. Design simple experiments to test hypotheses.
go5. Use laboratory skills in performing (simple experiments).
go6. Interpret experiment data.
go7. Describe clearly the experiment.
go8. Remember the idea of an experiment over a long period of time.

Domin (1999) developed a taxonomy and distinguished four different laboratory instruction styles (Table 1).

Table 1. Descriptors for the laboratory instruction styles. Based on (Domin 1999)

Style	Descriptor		
	Outcome	Approach	Procedure
Expository	Known	Deductive	Provided by teachers
Discovery	Known	Inductive	Provided by teachers
Problem based	Known	Deductive	Generated by students
Inquiry	Unknown	Inductive	Generated by students

The 'outcome' descriptor deals with the results students obtain during the laboratory class: Are those already known or unknown? The 'approach' descriptor deals with the type of reasoning taking place during the laboratory class. In the 'deductive' approach, theoretical concepts and principles are illustrated by the experimental results. In the 'inductive' approach, theoretical concepts and principles are constructed based on the experimental results. The 'procedure' descriptor deals with the mode of delivery of procedures (laboratory methods, research strategies): Are these provided by teachers or should students generate them?

There has been discussion in literature about which objectives should be achieved in the laboratory class and by which laboratory instruction style these objectives should be achieved (Kirschner & Huisman 1998; Johnstone & Al-Shuaili 2001; Reid & Shah, Iqbal 2007). It is outside the scope of this thesis to contribute to this discussion. With (Domin 2007) it is presumed that each laboratory instruction style possesses unique strengths and weaknesses and that there is no such thing as 'the' instruction style most suited to reach all objectives for all students in each phase of their study program. In the following section the learning objectives for laboratory education at LoFC are discussed.

Objectives of food chemistry laboratory classes

The objectives of LoFC laboratory classes are as follows (not in order of importance).

The first objective is to let students experience the authentic environment that plays a key role in food chemistry research: the laboratory. Although most food chemistry researchers manage to publish clear tables and figures in their research papers, the road leading to those tables and figures can be strewn with pitfalls and failures. For example: obtaining inactive or polluted enzyme extracts from third-parties and obtaining ambiguous results, forgetting to include a blank sample and obtaining meaningless results. It is difficult to relate this objective to one of the 8 general objectives of laboratory classes mentioned before (go1-go8). This has to do with the complex nature of food chemistry laboratory classes. Students are not performing simple acid-base titrations during these classes, but a sequence of interrelated experiments involving complex food systems and sophisticated analytical equipment to purify, characterise and modify individual constituents. Hence, students should experience this complexity of food chemistry laboratory work.

The second objective of the laboratory classes at LoFC is that students perform the 'learning task' (Merrienboer & Kirschner 2007) of scientific inquiry and problem solving in that authentic laboratory environment. This objective involves designing, re-designing, planning and carrying out research strategies (go1, go2, go4) and interpreting and evaluating experimental data (go6). Learning to design and re-design research strategies can for an important part take place outside the laboratory (Kirschner & Huisman 1998). The supervisors at FCH feel that there are differences between designing and re-designing your own laboratory class research, and doing this because of a 'dry' assignment on e.g. the computer.

Using the vocabulary of Merrienboer & Kirschner (2007): During the laboratory class students are stimulated to learn to coordinate constituent skills, thus facilitating the transfer of what is learned to a new situation, that is, the situation the graduated student faces when he or she works in industry.

The third objective of laboratory classes at LoFC is to get acquainted with the experiments used in food chemistry research (go8). They should know what experiments are available for what operations (e.g. what experiments can be used to determine the protein content of a sample), and remember in what circumstances a particular experiment is more suitable than another experiment. This is to reinforce the knowledge about these experiments obtained during the lectures.

The fourth objective of the laboratory classes at LoFC is that students learn to meaningfully, correctly, efficiently and safely carry out laboratory method steps (go5). *Meaningfully*: Students should know why they are carrying out a laboratory step and why the step is the way it is. This is particularly important in circumstances in which unexpected things happen. First of all, students should be able to detect when something is unexpected, so they should know what to expect. Second, like stated before, lab work, and especially lab work in a laboratory with 100-150 peers, tends to pose small but important practical challenges on the (future) researcher. Chemicals can temporarily be out of stock, solutions can start to precipitate, equipment can break down, etc. In most cases these challenges can be met by taking small detours from the laboratory method step text. To be able to take the correct detours, one should know exactly what is happening and why. *Correctly*: Students should get reliable results when they finished the laboratory method. This is partly done by correctly translating the laboratory method text into actions and partly by gaining and making use of 'tacit knowledge'. Tacit knowledge is the "indescribable or tacit, feeling or awareness of what is happening or what is supposed to happen, as opposed to the explicit knowledge of how or why something works" (Kirschner & Huisman 1998). *Efficiently*: Research is often bound to time and financial constraints, and students should be able to carry out practical actions swiftly. *Safely:* Students should not only *know* how to work safely (which often comes down to a few easy to remember rules), they should also *do* it, even when they are carrying out the method step for the umpteenth time and under time pressure.

The fifth objective of the laboratory classes at LoFC is that students learn to communicate their work to their peers and supervisors (go7). This not only after laboratory work, in the form of a report or presentation, but also during laboratory work e.g. in daily work meetings. According to employers in food industry, 'communicating' is the most desired skill for nowadays food scientists and technologists (Flynn et al. 2012).

Instruction styles of LoFC laboratory classes

Traditionally, B.Sc. laboratory classes at LoFC were of the expository laboratory instruction style. The M.Sc. laboratory classes were of the inquiry style. Since 2006 LoFC is gradually changing the instruction styles of the B.Sc. laboratory classes by introducing 'inquiry' and 'problem based' elements. For example: students of the B.Sc. course 'Food Chemistry' have to design their own research strategy based on a list of assignments, instead of following the exact procedure outlined by teachers. In line with (Merrienboer & Kirschner 2007), the aim is to include all Food Chemistry learning objectives in all LoFC's laboratory classes. The difference between the laboratory classes is the amount of support students get: From a high level of support during the laboratory class of the B.Sc. course 'Nutritional Aspects of Foods', to a low level of support during the M.Sc. 'Advanced Food Chemistry'.

● The model courses 'Food chemistry' and 'Food Ingredient Functionality'

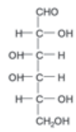
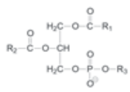
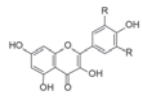
Two courses of LoFC served as 'model courses' during the research presented in this thesis: The B.Sc. course 'Food Chemistry' and the M.Sc. course 'Food Ingredient Functionality' (each 6 ECTS credits). 'Food Ingredient Functionality' is organised by LoFC in cooperation with the Food Physics Group at Wageningen University. The learning objectives of both courses are listed in Table 2. Most general learning objectives of 'Food Chemistry' are related to remembering, understanding and applying knowledge.

Table 2. Learning objectives of the two model courses.

Food Chemistry (B.Sc.)	Food Ingredient Functionality (M.Sc.)
1. recognize the molecular structure of the most common food constituents; 2. explain the generic functional and chemical properties of the most common food constituents; 3. recognize the, for food important, chemical and biochemical reactions; 4. explain the effect of (bio)chemical reactions on the characteristics of a food product in a qualitative sense; 5. translate qualitative effects into quantitative judgements; 6. choose and apply the, for food analysis, most basic analytical methods and techniques; 7. to plan, carry out and evaluate experiments for investigation of the major chemical changes that occur in a food raw material during processing to a food product;	1. explain the mechanism of the techno-functionality or bio-functionality of ingredients; 2. explain why ingredients with similar chemical structures can have different techno- and bio-functionalities; 3. explain how ingredient functionality can be influenced by processing; 4. predict and explain the effect of the interaction between ingredient and complex food matrix under different conditions; 5. make deliberate choices in application of ingredients; 6. choose and conduct experiments to analyse chemical properties and the techno-functionality of ingredients;

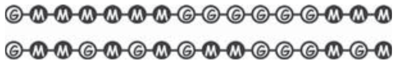
During this course students are given a broad introduction to the field of food chemistry (Table 3). The main constituents of food (carbohydrates, proteins / peptides / amino acids, enzymes, lipids and phenolic compounds) are discussed in detail. Students should learn the classification of these constituents, the important structural formulas, the most common reactions in food systems, quantitative aspects (e.g. solubility and enzyme kinetics), the methods used to analyse the constituents and the applications of the constituents in food products. Students should also be able to translate food chemistry related problems into mathematical equations, and have a quantitative understanding of reactions occurring in food and industrial food processing. The course is supported by a number of e-learning modules focussing on the theory and quantitative aspects (Diederen et al. 2003; Diederen et al. 2005). Generally speaking, the course 'Food Chemistry' can be seen as the foundation on which the other courses of LoFC build, as food chemistry knowledge is the main output

Table 3. Overview of theory of the B.Sc. course 'Food Chemistry'.

Topics:	Examples:
• classification	monosaccharides, aliphatic amino acids, hydrolases, saturated fatty acids, hydroxybenzoic acids, D-xylose, L-serine, hydrogen peroxide, stearic acid, caffeic acid
• structural formulas / structures	   
• most common reactions during processing and storage	caramelization, Maillard reaction, isomerization of glucose to fructose, photo oxidation, oxidation of phenolic compounds
• quantitative aspects	solubility, Michaelis–Menten kinetics, peroxide value
• analysis methods	analyzing reducing sugar content, electrophoresis, TBA test
• applications in food products	thickening agent, soup flavors, removal of oxygen with glucose oxidase, change crystallization behaviour by hydrogenation of lipids, aroma compounds

The 'Food Ingredient Functionality' course focuses on the correlation between the structure of important ingredients and their physical, bio-active and sensory properties (Table 4). Compared to the previously described 'Food Chemistry' course this course is much more linked to the practice of research within the food industry, where researchers should make deliberate choices for ingredients. These ingredients are often mixtures of various constituents, which can strongly influence the techno-functionality (e.g. whether it is a gel or a viscous solution) or bio-functionality (e.g. whether health effects occur) of the food system. Students should be able to predict these influences and deal with them. In order to do so, students should know the molecular diversity in food ingredients and the relation between structure and function of food constituents. Students should also be able to modify ingredients to obtain a certain bio- or techno-functionality. In addition, students should know the basic mechanisms of chemical deterioration and how to prevent that type of deterioration. The food physics topics include the roles of attractive and repulsive interactions between food ingredients, the rheological properties of food, the diversity in gels and the interactions and stability in emulsions.

Table 4. Overview of theoretical part of the M.Sc. course 'Food Ingredient Functionality'

Food chemistry topics:	Examples:
• molecular diversity in food ingredients	Two alginates having identical sugar compositions, but different distributions of guluronic acid (G) and mannuronic acid (M). 
• structure-function relationships	Guluronic acid blocks provide calcium-sensitivity, which is essential for making gels.
• few key constituents in mixtures	In protein hydrolysates, few peptides are amphiphilic and can act as surfactant in stabilisation of emulsions.
• modification of ingredients	Acylation of sterols with fatty acids to improve solubility in the oil phase of margarine.
• chemical spoilage and how to prevent it.	Fat oxidation, which can be prevented by adding antioxidants.
Food physics topics:	**Examples:**
• role of attractive / repulsive interactions between food ingredients	Irreversible aggregation of protein particles due to van der Waals interactions. Stability in protein solutions due to electrostatic repulsion based on charge density
• rheological properties of food	Emulsions and polysaccharide solution often show a shear thinning behavior.
• diversity in gels	Proteins often form particles gels, polysaccharides often form polymer gels.
• interactions and stability in emulsions	Provide stability to emulsions by using protein-polysaccharide interactions by changing environmental conditions.

The differences between 'Food Chemistry' and 'Food Ingredient Functionality' are reflected in the characteristics of the laboratory classes of both courses (Table 5). The main difference between those laboratory classes is that the 'Food Chemistry' laboratory class more resembles the 'expository' type, whereas the 'Food Ingredient Functionality' laboratory class more resembles the (supported) 'inquiry' type laboratory class.

Table 5. Characteristics of the 'Food chemistry' and 'Food ingredient functionality' laboratory classes.

	Food Chemistry (B.Sc.)	Food Ingredient Functionality (M.Sc.)
Number of students (in 2012)	110	142
Student group size	3	7
Most resembling style	Expository	'Supported inquiry' (students do receive guidance)
Outcome	Known	Mostly unknown (first part: known)
Approach	Deductive: principles are illustrated by experiments	Inductive: principles are discovered by experiments.
Relevant learning objectives in Table 2	3, 6, 7	All
Research strategy	Designed by students, guided by list of assignments.	Designed by students
Number of experiments to choose from	~32 from a list.	~26 from a list, but many more from literature.
Degrees of freedom	Almost none: there is one 'correct' research strategy, only minor deviations are possible.	Many: there are many correct research strategies.

Both laboratory classes will now be discussed in more detail. An important aim of the 'Food Chemistry' laboratory class (duration: 15 days x 4 hours) is to let students get hands-on experience with the most basic food chemistry experiments (Table 2, goal 3 and 6). For example: dry matter content determination, SDS gel electrophoresis, protein content according to Bradford, reducing sugar content according to Nelson Somogyi and the TBA test. Students work in groups of 3 students. Each group works on one raw material (e.g. barley) and should investigate major chemical changes during simulated processing (e.g. beer brewing). Groups are given ~20 assignments, e.g. "Determine the influence of reducing compounds on the browning reaction during deep frying", "Investigate the relation between solubility and pI of the protein isolate", "Test the stability of pectin in acidic/alkaline environments", "Simulate the mashing process of barley". Guided by these assignments, groups start the laboratory class by designing a research strategy consisting of experiments (goal 7). These experiments can be chosen from a list of ~5 experiments to purify constituents from their raw material, 11 experiments to analyze carbohydrates, 8 experiments to analyze proteins, 7 experiments to analyze lipids, an experiment to analyze phenolic compounds and the method 'determination of dry matter content'. After the design and planning are approved by the supervisors, groups start their practical work by mimicking a process typical for food technology, e.g. the mashing of barley in the beer brewing process. When this process is finished, groups start isolating/analyzing the main components (carbohydrates, proteins, lipids, phenolic compounds) from the processed foods obtained. The rest of the laboratory class is aimed at characterizing and quantifying the isolated compounds. Groups should describe their results, discussions and conclusions in a report, which forms the basis for their assessment together with their working attitude.

An important aim of the laboratory class of 'Food Ingredient Functionality' (duration: 15 days x 4 hours) is to teach students to make informed decisions on experiments and ingredients (Table 2, goal 6). With respect to experiments: Given a research question students should take into account the various suitable experiments and decide which experiment is most appropriate in the current situation. Students should also learn to make informed decisions on the use of ingredients when designing a food system. The reasoning behind these decisions is similar to informed decisions on experiments. To obtain a certain techno-functionality or bio-functionality, one or more ingredients are available. Based on the chemical and physical properties of these ingredients, their interaction with other constituents in the food system and their availability and costs, students should make a decision for a certain ingredient (goal 6). Students work in groups of 7 students. Each group receives an assignment, consisting of 3 parts. For the first part of the assignment, groups design a research strategy to identify about 5 different food ingredients (goal 1, 2 and 6), e.g. 5 different polysaccharides. For the second part of the assignment, groups design a research strategy to demonstrate the influence of various conditions on a model system made with a selection of the food ingredients identified during the first part of the assignment (goal 3-6). For example: The influence of both slow- and fast-release calcium on the formation of alginate gels. For the third part, groups should design a research strategy to create a model system of at least two ingredients from different ingredient categories. For example: Inhibiting drainage of a protein-stabilized foam by adding alginate to the continuous water phase. The outcomes of the last two parts of the assignment are unknown to supervisors. Similar to the laboratory class of ‘Food Chemistry’, groups are provided with a list of food chemistry and food physics experiments they can use in their research strategies. However, groups are also encouraged to add their own experiments, e.g. experiments found in literature. After supervisors approved the strategy for the first part of the students, students start performing experiments. The second and third part of the assignment require students to perform some initial experiments and decide to do one or more follow-up experiments based on the results of the initial experiments. At the end of the laboratory class groups should prepare a presentation. In this presentation students should emphasize the food chemistry and food physics aspects behind their research. For example: They should provide mechanisms which explain the results obtained. Groups are assessed based on this presentation and their working attitude.

Design oriented research

In this research a faculty based design oriented research approach (DORA) is used. This approach implies the following research questions (Hartog et al. 2010):

1. “what are, in a specific real university context, goals that make sense and why,
2. how can these goals be articulated in terms of measurable quantities,
3. is it possible to achieve these goals,
4. if so, how?”

To a large extent, design oriented research involves constraint exploration efforts (Jonassen 2008; Gross 1985). Thus, the design goals and their articulation in terms of design constraints are output rather than input of DORA research (Hartog et al. 2010). In DORA, scientific theories, technologies and subject matter resources can be considered as the tools and bricks with which artefacts are created. In DORA, scientific models, technologies and content matter resources are approached as much as possible via their respective interfaces. For example, in the case of a software library, public functions offered by the library are used, not private ones. In the case of an educational theory, explicit design constraints (if available) are followed instead of deducing own design guidelines from theory. In the case of subject matter - in this case: food chemistry - existing contents are used, instead of making changes to the contents. The created artefacts are implemented and evaluated in a 'real' educational setting.

Because of the real education setting, the research presented in this thesis was subjected to many constraints. The artefacts should be tested and used in an ordinary laboratory class organized by LoFC. As courses of LoFC are given once a year, there was only a single opportunity per year to obtain evaluation results. The coordinator of the laboratory class who is responsible for the quality and goals of the laboratory class, has a major voice in the design choices. As it is intolerable that students fail the laboratory class because of some educational experiment, students were free to decide if they wanted to use the artefacts or not. Similarly, artefacts were also not allowed to turn existing educational practices 'upside-down'.

The remainder of this introduction chapter is dedicated to defining the goals of the research presented in this thesis.

Challenges in the model laboratory classes

The model food chemistry laboratory classes posed challenges for both students and supervisors, which will be discussed in this section. Based on these challenges sensible research goals will be formulated.

Students having mental overload

During a number of years, supervisors at LoFC noted that many students exhibit behaviour typified by Johnstone and Letton (1990) as "…following instructions line by line without much effort to consider the theoretical aspects which ought to illumine and inform their observations". This behavior could be caused by the overloading of the limited 'working memory' people have (Johnstone 1997). Bannert (2002) writes: "(...) one major assumption [of the cognitive load theory] is that a human's working memory has only a limited capacity. When learning, humans allocate most of their cognitive resources to this activity, and in many cases it is the instructional format which causes an overload. Consequently, the basic idea is to reduce such external load in order to make more capacity available for actual learning so that better learning and transfer performance is achieved." This makes it a sensible goal to avoid extraneous cognitive load induced by the instructional format of the laboratory class.

Students start not well-prepared

Preparation is of crucial importance for a laboratory class (Johnstone 1997). According to supervisors at LoFC students often start not well-prepared in the laboratory class. Although they finished three weeks of lectures, they often lack theoretical background knowledge. Consequently, students often do not know what is expected from them, nor what to expect during the laboratory class. A sensible goal of the research presented in this thesis is to let students prepare for their laboratory experiments.

Communication on research strategy not formalised

In both model laboratory classes students work in groups, which have to design a research strategy (Table 5). During the laboratory class, there are discussions between group members and group members and supervisors about the research strategy. This to see if there is progress and if the research strategy has to be adapted due to new information. According to supervisors at LoFC, there was noise in the communication because students used different layouts for their designs. For example, supervisors indicated they had to allocate time and cognitive resources to understand what groups meant with their designs. As a consequence, these could not be used for e.g. critically thinking about the science behind the designs. This makes it a sensible research goal to support the communication between students and between students and supervisors.

Student freedom vs. supervisor control

The organization of an inquiry type laboratory class can be a challenge for teachers (Domin 1999; Johnstone & Al-Shuaili 2001). This has to do with the intrinsic nature of these laboratory classes: Students having the freedom to design and plan their own work, leads to the situation that supervisors have less control over what is happening in the laboratory. Furthermore, during the 'Food Ingredient Functionality' course, students have to work with sophisticated analytical equipment, which is also used by B.Sc., M.Sc. and Ph.D. thesis students at LoFC. Consequently, measuring time is scarce during the laboratory class, and should be divided over multiple groups. This makes 'giving students the freedom to plan their experiments without supervisors losing control and without risking overbooking of equipment' a sensible design goal.

E-learning and laboratory classes

E-learning has become an integral part of the education at most universities. Various e-learning activities have been developed to support laboratory classes:

1. Pre-laboratory learning activities, aiming to prepare students for the laboratory class. Examples: The Dynamic Laboratory Manual, consisting of videos, simulations and quizzes (Harrison et al. 2011) and digital assignments on research experiments (Diederen et al. 2006).
2. Virtual laboratory learning activities, aiming to attain (some of) the learning objectives of the laboratory class. Examples: The Virtual ChemLab (Woodfield et al. 2004), in which chemistry experiments are simulated and a virtual reality laboratory (Riganelli et al. 2005), in which students can perform a laser refractometry experiment. Virtual laboratory learning activities can also be used as a pre-laboratory exercise (Dalgarno et al. 2009).
3. Remote laboratory learning activities, in which students perform real experiments by controlling equipment via the internet. Examples: a remotely controlled experiment for determining the rates of fast chemical reactions (Senese & Bender 2000) and a remote spectrophotometry experiment (Cedric d'Ham et al. 2004).
4. Post-laboratory learning activities, which aim to support students in data analysis. Example: A module assessing result that students have obtained in an acid-base titration (Nicholls 1999).

As these activities mainly take place outside the laboratory, a design opportunity could be to support both students and supervisors inside the laboratory using computers. Such a support system (further referred to as 'laboratory electronic performance support system' or 'labEPSS') could be helpful in meeting the challenges of the model laboratory classes mentioned before. Various definitions of an 'electronic performance support system' have been proposed in literature:

- "the electronic infrastructure that captures, stores and distributes individual and corporate knowledge assets throughout an organization, to enable individuals to achieve required levels of performance in the fastest possible time and with a minimum of support from other people." (Raybould 1995)
- "a computer-based system that provides integrated support in the format of any or all of the following: job aids (including conceptual and procedural information and advice), communication aids and learning opportunities (such as Computer-Based Training (CBT), in order to improve user performance." (McKenney et al. 2008)
- "computer-based systems that are developed in order to increase performance; are used in the actual work environment; are related to topic field; and provide content-focused information." (Kert & Kurt 2012)

In the context of this thesis, the following notions within these definitions are important. Firstly 'in the actual work environment'. This notion is important to define the niche of labEPSS within the array of e-learning activities related to laboratory education. LabEPSS should support students and supervisors in the laboratory classes, while students are carrying out experiments. Secondly 'integrated support'. LabEPSS could provide procedural information at one physical location, e.g. the computer screen. Thirdly, 'learning experiences' or 'learning opportunities'. The main aim of labEPSS is to support learning, and not 'just make life easier in the laboratory'. LabEPSS could offer pre-laboratory assignments to let students prepare for their laboratory class, e.g. an assignment in which students design a research strategy. The *results* obtained during these assignments (e.g. the research strategy itself) could then support students while working in the laboratory. Fourthly, 'communication aids'. LabEPSS could formalize the way students communicate their research strategy by offering templates. The system could also capture the 'design rationale' of the research strategy: an explanation of why the design (in this case: the research strategy) is the way it is (Lee & Lai 1991). Additionally, based on the research strategies and planning information, labEPSS could give teachers instant clues about what students are doing in the laboratory class. Fifthly and finally, 'captures, stores and distributes (…) knowledge assets'. LabEPSS could offer a central location where students store their research strategy and results. This information would then be made accessible for other students (in the case of group work) and supervisors. Furthermore, labEPSS could assist supervisors, e.g. by answering the factual questions students have, which frees up time for conceptual questions.

An extensive search in SCOPUS and Scholar using combinations of the terms 'laboratory', 'practical', 'chemistry', 'education', 'performance support', 'laboratory information system', 'computer-aided', 'computer supported', 'computer aided', 'computer assisted' did not result in articles describing a labEPSS. So to our knowledge, such a labEPSS for chemistry laboratory classes does not exist yet.

Aim and outline of thesis

This thesis aims to describe the design and evaluation of a laboratory electronic performance support system (labEPSS) designed to reach the goals described before.

In chapter 2 a web-based laboratory manual (webLM) is described. Students can access webLM using a computer at their laboratory bench. The webLM contains the laboratory manual text and additional information on the theoretical background of method steps, procedural information, images and locations of equipment and chemicals. WebLM makes use of the advantages web pages have over printed text: Extraneous cognitive load is avoided by presenting procedural information just-in-time and physically close to related information.

In chapter 3 a web-based experiment design tool (ExperD) is described. Students can use ExperD to design their research strategy for the laboratory class in the form of a workflow of experiments. During the laboratory class, this workflow supports students because it gives them the overview over the research being carried out. Because it offers a predefined way of communicating a research strategy (workflow of experiments), ExperD helps students and supervisors in their communication.

In chapter 4 the potential of smartphones and tablets for supporting students in the laboratory class is explored. Increasingly, students have smartphones and smartphone apps appear on the market which can support students in the laboratory. The multiple app supported laboratory can become awkward, as using apps and switching between apps (and between apps and other information resources in the laboratory) is likely to induce extraneous cognitive load. In the chapter the design of a web based app, LabBuddy, is described, offering integrated access to various information resources.

In chapter 5 a computer assisted learning scenario is described, helping supervisors in managing the 'Food Ingredient Functionality' laboratory class. This scenario consists of a pre-laboratory exercise, in which student groups design a research strategy using ExperD. Students also book sophisticated equipment using ExperD, which imposes constraints on the number of samples groups can process, to prevent the overbooking of equipment.

In the last chapter, chapter 6, the design of the complete labEPSS is described. This description includes design constraints of both the realized components as well as additional components based on theoretical considerations.

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2. Students using a novel web based laboratory class support system: A case study in Food Chemistry education

Abstract

The design, usage and evaluation of a web based laboratory manual (webLM) are described in this chapter. The main aim of the webLM is to support students while working in the laboratory by providing them with just-in-time procedural information. The webLM was introduced in the B.Sc. course 'Food Chemistry' at the Wageningen University. The evaluation showed a positive attitude towards the webLM by both students (n=79) and supervisors (n=4). Furthermore, the webLM can be a promising research tool that can monitor student behavior in the laboratory classes.

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Introduction

Food chemistry education is regarded as an essential part of the academic curricula of Food Technology at Wageningen University. One characteristic of the B.Sc. food chemistry courses is that they aim to familiarize the students with a range of research methods (Diederen 2005). These research methods are mainly taught during laboratory classes. In this article we describe the design, usage and evaluation of a novel web-based laboratory class manual, aiming at supporting students while working in the laboratory.

The laboratory class of the B.Sc. course 'Food Chemistry'

The morning course 'Food Chemistry' (6 ECTS-credits) at Wageningen University in the Netherlands consists of two parts. In the first three weeks students attend lectures and practice with the theory using digital exercises. The next three weeks are dedicated to a laboratory class. In this laboratory class students work in groups of 2-3 students. Each group is given a raw material (e.g. barley) and investigates major chemical changes during processing (e.g. beer brewing). Students are given a list of laboratory methods and a set of assignments, with which they have to make a design and a time planning of their laboratory class.

From discussions with our students we know that most of them experience the laboratory class as difficult. Students have to know a large number of facts before they can make sense of what is happening during the experiments and before they can correctly interpret the results. Furthermore, students are confronted by new laboratory methods and new equipment in our laboratory class. We therefore think that the difficulties students face in our lab classes can be elucidated by the focusing on the mental load of the students during laboratory work.

Mental load in our laboratory classes

At the beginning of our research we interviewed the most experienced laboratory supervisors (n=4) of the course 'Food Chemistry' and asked them to list the most common student questions during the laboratory class. They unanimously came up with 'low-level' questions like:

- Where can I find…? Where should I put…?

- When can I do…?
- How does …. look like?

The supervisors also mentioned that 'higher-level' questions e.g. on experiment design or evaluation of results, are seldom asked by students. Furthermore, supervisors mentioned that answering the 'low-level' type of questions requires most of their supervision time.

The fact that almost no 'higher-level' questions are being asked suggests student behavior that is characterized by Johnstone and Letton as: "…following instructions line by line without much effort to consider the theoretical aspects which ought to illumine and inform their observations" (Johnstone & Letton 1990). In another paper (Johnstone 1997), Johnstone relates students' difficulties in chemistry laboratory classes to the overloading of so-called 'working memory'. People have a limited working memory (Miller 1956). This working memory can hold approximately up to 7 (±2) 'chunks' of information at the same time. If a certain problem requires the learner at one time to have too many chunks of information in his or her working memory, working memory may become 'overloaded' and the problem solving process is hampered (Sweller 1994). The cognitive load a problem induces is related to the problem's complexity, the learner's knowledge or the way the problem is presented (Bannert 2002; Sweller 1994).

Role of the laboratory manual

In our laboratory classes students perform experiments using a laboratory manual containing several methods. A typical chemistry laboratory method consists of two basic components: An introduction and a numbered list of method steps, the 'recipe' (Figure 1).

Each method step has implicit aspects, required to successfully and efficiently carry out the experiment (Table 1). These aspects are usually well-known to an expert, but unknown to students unfamiliar with the experiment. These implicit aspects can induce cognitive load (Johnstone & Letton 1990). Furthermore, instructional formats requiring learners to mentally combine different sources of information before understanding occurs, can cause high cognitive load and (negatively) affect learning (Chandler & Sweller 1991; Clark & Mayer 2007). Lowering this type of cognitive load by integrating illustrations of the equipment in the manual text indeed resulted in improved learning outcomes (Dechsri et al. 1997; Haslam & Hamilton 2009). Finally, Van Merrienboer & Kirschner (2007) advocate 'just-in-time' provision of procedural information i.e. while they are carrying out a laboratory method.

1. Simulation of the Mashing process.

Introduction

During the conversion of barley to malt (by germination) **enzymes** are formed. These enzymes become active during the "mashing" step. **Mashing is the mixing of milled malt with water**, until a thick batter is formed. This batter is heated according to a certain temperature/time schedule. During mashing the alpha- and beta-amylases start to **degrade starch** to small carbohydrates. In particular maltose is formed, but also some glucose, maltotriose and larger gluco-oligosaccharides. These carbohydrates can be measured as "reducing sugars". **Proteins are degraded** by proteases to (small) peptides and free amino acids. This can be measured as an increase of the number of free amino groups, or by electrophoresis (SDS-PAGE).

Method

1. Make an enzyme extract from malt by mixing 5 g of malt and 20 ml of water in a mortar Let it soak for 15 min.
2. Transfer the enzyme extract to a clean test tube, and store it at 4 °C in a sample refrigerator.
3. Grind 100g barley using the Retsch mill (⚠). Ask your supervisor how to operate the

Figure 1. A typical laboratory method, taken from the laboratory manual of the course 'Food Chemistry'.

Table 1. Implicit aspects of laboratory method steps. Students need to know these aspects to successfully, safely and efficiently carry out the experiment.

- Which equipment to use for common laboratory operations (e.g. one can use a beaker glass to add a liquid)
- What chemicals and equipment look like.
- Where chemicals and equipment can be found.
- Hazards related to chemicals and equipment.
- Time needed for each method step.
- Whether the method step can be paused or not.
- How to perform the step / how to operate equipment.
- What the step's pitfalls are and how to avoid them.
- The relationship between theory and the operation in the step (the 'why' of the step).

Web-based laboratory manual might offer opportunities

Incorporating the implicit aspects listed in Table 1 into the printed laboratory manual might generate an increase of unnecessary cognitive load. For example:

One could add a table to the printed manual, in which all materials and locations are listed, but this would lead to extensive leafing through the manual. The main advantages of web technology over printed text books (Table 2) make a web-based version of the laboratory class manual an interesting alternative of the printed version. Such a 'web lab manual' could support students while working in the laboratory, by giving them just-in-time access to information they would otherwise have obtained from their supervisors or peers. To our knowledge, no such web-based laboratory manual currently exists. Another opportunity of using web technology is that it makes extensive student logging possible. Each mouse click or keyboard usage can easily be stored into a database and used for later analysis by teachers and/or educational researchers.

Table 2. Main advantages of web text over printed text (Clark & R.E. Mayer 2007; Brusilovsky et al. 1998)

- Can provide information just-in-time (and thus reduce unneccesary cognitive load).
- Can be relatively cheap to develop, maintain and distribute.
- Can provide tailored instruction, e.g. by hiding information to more experienced students,
- Can be interactive.
- Can provide animations / videos.
- Can provide quick access to information (hyperlinks and search functionality)

Research aims

The aim of this research was to design, implement and evaluate a web-based laboratory manual (webLM), dealing with the problems described before. Furthermore, the project aims to give answers to the following research questions:

1. Is it possible to design, realize and implement a web-based lab manual that
    a. students prefer to use over a printed version?
    b. supervisors see as a valuable addition to the laboratory class?
2. Can the web-based lab manual be used as a research tool to monitor student behavior in the laboratory class?

Design-oriented approach

Because it is impossible to answer above research questions without a webLM, a design oriented research approach is chosen. Design oriented research aims at the production of new knowledge by designing and realizing a new artifact (Busstra

2008). To guide the design process, we adapted a design oriented research model described by Verschuren & Hartog (Verschuren & Hartog 2005; Hartog et al. 2010).

Design assumptions and requirements

We assumed that laboratory class teachers will not want to invest much time (max 1.5 hour per method) in conversion of any available printed manual into a web-based manual. In the laboratory, there should be sufficient computers with internet connections available on the laboratory benches. The webLM methods are provided as standard web pages, so they can be shown by all HTML-capable devices.

Table 3. Design requirements and evaluation measures for the web lab manual

#	Design requirements, the design should	Evaluation using student questions*, supervisor interviews or monitoring of actual use
d1	Help students while doing experiments by giving them *in situ* access to the webLM	• Questions concerning computer usage and student appreciation. • Measure webLM usage • Supervisor's opinion.
d2	Be easy to use and have a clear user interface	• Ask whether students find the different aspects of the webLM clear and easy to use. • Ask and observe whether students prefer to use the printed or the e-lab manual.
d3	Help students in planning their experiments.	• Ask whether students find the time table / visual aids helpful.
d4	Help students to work efficiently	• Ask whether the webLM saved students time/effort. • Ask and observe whether students prefer to use the printed or the e-lab manual. • Supervisor's opinion. • Count the number of times students access the 'where'-information.
d5	Be flexible, easy to maintain everywhere and anytime.	• Ask whether the supervisors find the system flexible and easy to maintain.

*) Evaluation questions have a five point Likert scale (1=disagree, 5=agree). Requirements are considered to be fulfilled when average rating is 4.0 or more and at least 75% of the students rate 4 or 5.

Finally, the webLM is implemented on a webserver that includes PHP and MySQL. Based on the considerations from the introduction, a set of design requirements and evaluation measures of the webLM were formulated (Table 3).

To ensure the quality of the webLM, design guidelines from literature were followed during the design process: use pictures when appropriate (Mayer & Moreno 2002; Dechsri et al. 1997), provide just-in-time procedural information (Merrienboer & Kirschner 2007) and prevent split-attention effect, improve spatial contiguity effect (Sweller 1994; Mayer & Moreno 2003; Sweller et al. 1998).

The web lab manual (webLM)

A prototype of the webLM was realized. The webLM's user interface is shown in Figure 2 and explained with comments in balloons as shown in Figure 3 and Figure 4. The webLM was incorporated in an electronic course book developed previously (Kolk et al. 2008). Because of this, students had access to other course elements, like the course book text and digital exercises. All in all, 50 laboratory methods having in total 481 method steps were added.

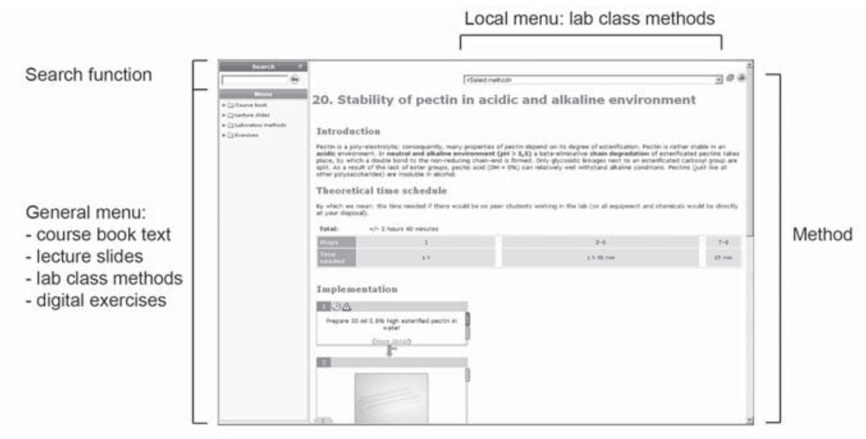

Figure 2. The overall screen layout of the electronic course book showing a method.

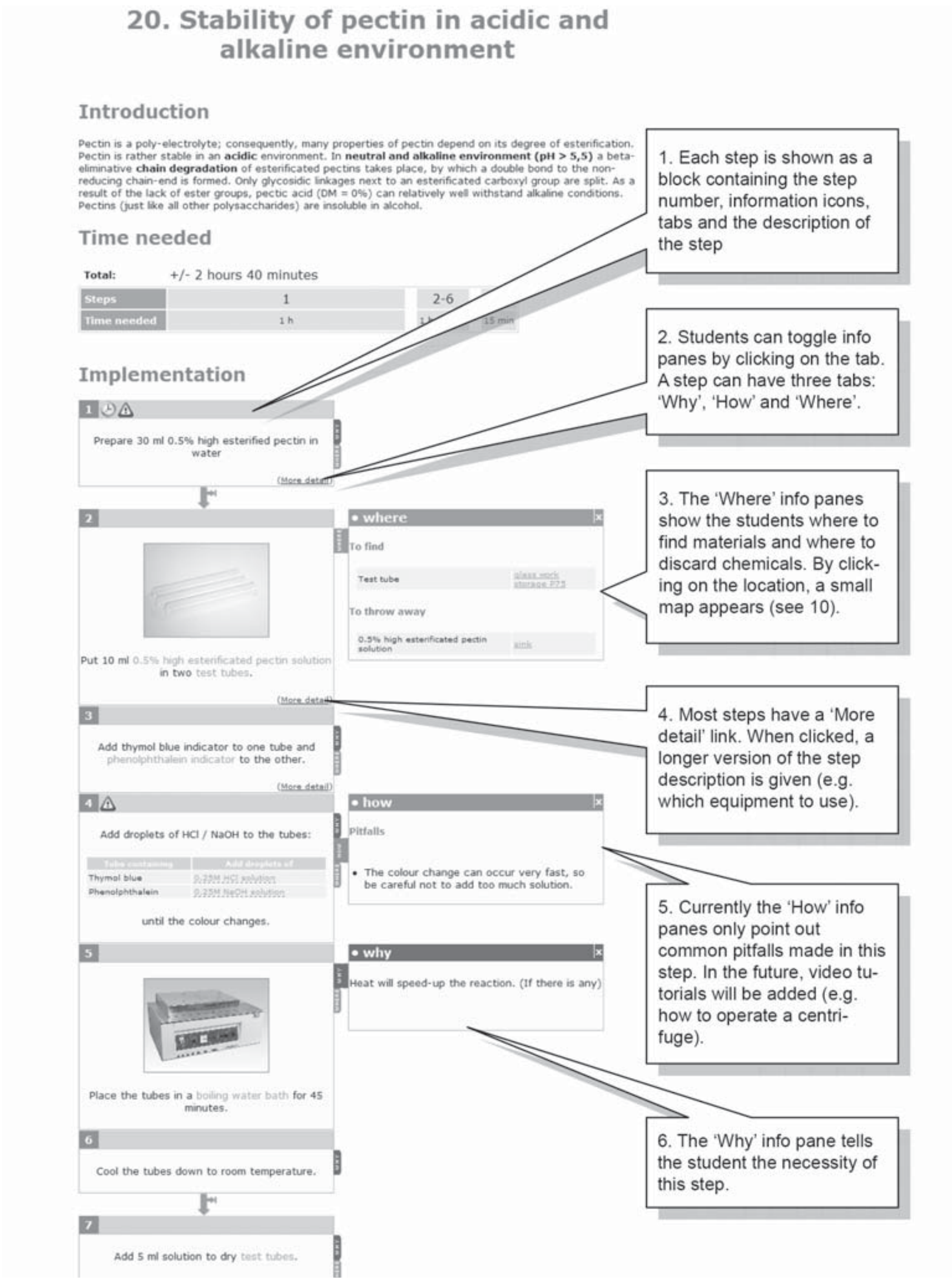

Figure 3. Detailed description of the webLM graphical user interface, showing almost a complete laboratory method.

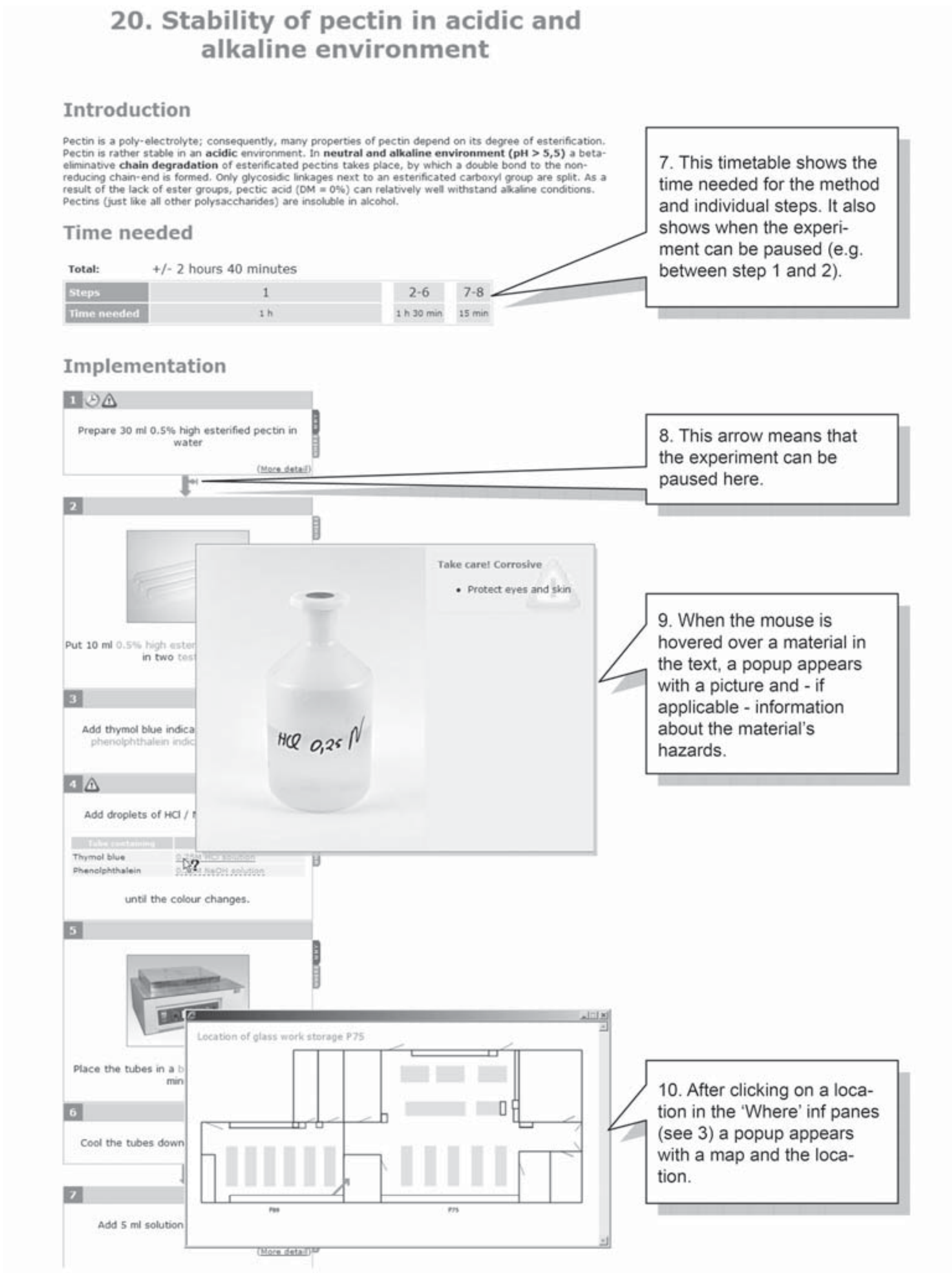

Figure 4. Detailed description of the webLM graphical user interface (continued).

Bringing the web lab manual to the laboratory

Desktop computers with an internet connection were installed on the lab benches, giving each group of 2-3 students access to one pc. On their pc students had access to Microsoft Office™, MSN messenger™ and a web browser. Besides the electronic version, students received a printed copy of the laboratory class manual. This printed version was similar to the version used in previous years. It contained the methods' introduction and the method steps' detailed content. Students were free to choose which manual they preferred during the laboratory class and could switch between the two versions at any time.

In total 79 students participated in the 2008/2009 laboratory class of the course 'Food Chemistry'. Students were distributed over 26 groups. These groups were supervised by 6 supervisors, of which 2 were new to this laboratory class.

Evaluation

Within the design-oriented approach of this project, the aim of the evaluation is to find out whether the design requirements are met (Verschuren & Hartog 2005; Hartog et al. 2010). For this, the design of the webLM was evaluated based on 1) the usage logging results, 2) a student questionnaire (n=74) held one week after the laboratory class had ended and 3) supervisor interviews held one month later (n=4).

Results

Every time the student opened a method or clicked a link or button this action was stored in the database. The logging results related to the webLM usage are plotted against time in the figures below. In Figure 5 the usage is split up per group. The figure shows considerable differences between groups: e.g. during the first week, some groups used the webLM up to four times more extensively than other groups.

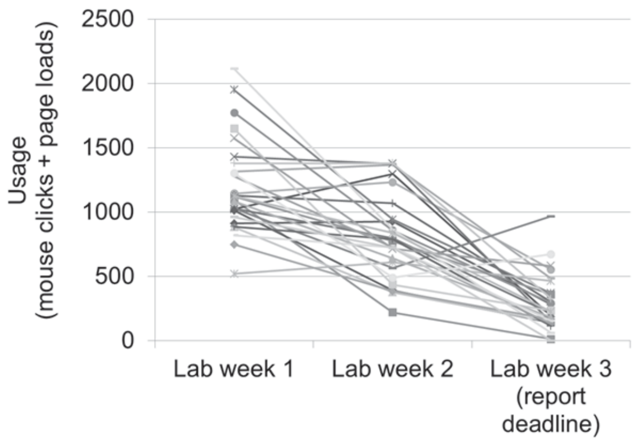

Figure 5 Number of webLM page loads and mouse clicks during the laboratory class, the self-study and the exam week, split up by group (n=26). Each block represents a group and groups are connected with lines. This figure shows the great diversity among usage among groups, some groups showing a four times higher activity than other groups.

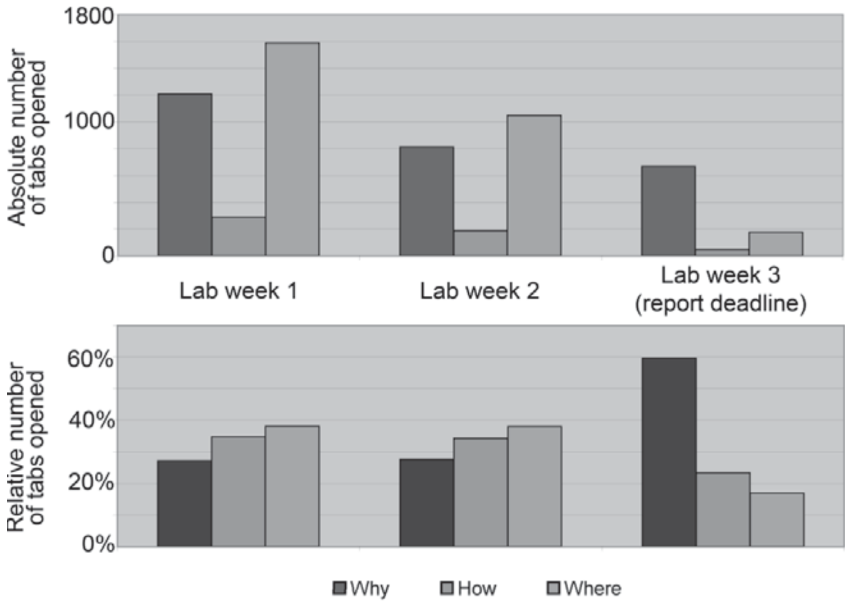

Figure 6. Absolute and relative number of times students opened an information tab during the laboratory class. To calculate the relative numbers, the absolute numbers were divided by the number of information tabs available (e.g. there are five times more ‘where’ tabs than ‘how’ tabs in the webLM) .

In Figure 6 the usage is split up per information tab, giving an indication of the students' information demand while advancing in the laboratory class. This figure shows that students clicked relatively more 'why' tabs in the last lab week, which is the week they had to hand in their report. The usage declines during the laboratory class because students start writing their report in the second and third week, and spend less time for experimenting. The results of the questions directly related to the design requirements are listed in Table 4 (the other questions being on detailed aspects of e.g. the user interface).

Table 4. Distribution of questionnaire results

#	Question	Answers (%)*					AVG
		1	2	3	4	5	(S.D.)
q1	Which of the two versions of the lab manual did you use the most while doing experiments*	49	34	7	6	4	1.8 (1.1)
q2	The webLM helped me in preparing for an experiment.	0	11	12	46	32	4.0 (1.0)
q3	The webLM helped me in doing the experiments.	0	1	5	34	59	4.5 (0.7)
q4	The e-lab manual is difficult to use	77	19	3	0	1	1.3 (0.7)
q5	Because of the e-lab manual I had the feeling I knew what I was doing during the experiments.	1	4	22	56	16	3.8 (0.8)
q6	While doing an experiment, the information in the 'Why' tabs helped me to understand why I was performing a step.	3	3	15	51	28	4.0 (0.9)
q7	I think I could carry out the experiments more *successfully* than with the printed manual alone.	7	8	24	28	33	3.7 (1.2)
q8	I think I could carry out the experiments in less time and with less effort than with the printed manual alone.	4	4	8	53	31	4.0 (1.0)
q9	The information in the 'Where'-tabs saved me time	3	7	14	38	38	4.0 (1.0)
q10	The pictures of equipment helped me to find [them]	0	4	7	43	45	4.3 (0.8)
q11	[The timetables] helped me to plan my experiments well	4	11	10	33	42	4.0 (1.2)
q12	I used the computer on my lab bench for	Calculations, e.g. in Microsoft Excel (n=46); writing the report (n=27); e-mail (n=56)					

*) 1 = disagree, 5 = agree

**) 1 = electronic version, 5 = printed version

During the supervisor interviews, the supervisors were confronted with student questionnaire results and asked for their opinion on the webLM in general.

In general, supervisors confirmed the picture that arises from the student questionnaire results. They did not recall any student having problems with operating the webLM. Besides that, the supervisors are convinced that the webLM saved them time, especially because they had to answer less low-level questions. This is in line with the usage logging results, showing e.g. that students opened the 'where'-tabs more than 2800 times during the laboratory class (Figure 6).

Discussion and conclusions

In this article we described the design, usage and evaluation of a web-based electronic laboratory manual. In this section we will discuss the results obtained using the research questions.

Is it possible to design, realize and implement a web-based lab manual which students prefer to use over a printed version? Our results indicate that most students strongly prefer the web-based lab manual over the printed version, and find the former one easy to use (q1, q4). They find the webLM very easy to use and helpful during laboratory work (q2, q3, q5, q6, q10, q11, q12). Students think the webLM made their lab work more efficient (it took them less time and effort to succeed in their experiments) than with the printed version alone (q7, q8, q9).

Is it possible to design, realize and implement a web-based lab manual which supervisors see as a valuable addition to the laboratory class? Although some supervisors had some objections to the webLM on beforehand (e.g. "students will not use it" and "I prefer the printed version") almost all objections disappeared during the laboratory course. Nevertheless, some supervisors argued that the webLM is not activating students to use the information offered. The webLM offers students much information supporting students to reach the laboratory class' learning goals, but it does not always offer an incentive to make use of this information. Making the webLM more interactive might be an interesting design challenge (see 'Future work' below).

One could argue that the webLM fosters students to blindly follow recipes and gather data without thinking of the purpose of the investigation. Our response to such criticism would be twofold: 1) Even the most experienced chemists follow recipes, and the webLM was designed to facilitate this part of research; 2) So, whether students are fostered to think about the purpose of the investigation is not within the scope of the webLM, but of the laboratory class as a whole.

Can the web-based lab manual be used as a research tool to monitor student behavior in the laboratory class? The webLM could prove to be an interesting tool in such research, because student behavior is being logged. Mining this data could result in objective information about student behavior in the laboratory class, information that otherwise could only be obtained by laborious monitoring. For example: There was great usage diversity among groups, some groups showing a four times higher activity than other groups (Figure 5). It would be interesting to know how these groups performed in the laboratory class. The logging data also gives clues about how many experiments a student or a group of students performs in parallel. This could be an indication of whether groups plan their work well, e.g. by performing experiments during the waiting times of other experiments.

● Future work

Now that we know that students prefer and use the web laboratory manual, the following design challenge arises: To extend the webLM, in such a way that it trains specific cognitive skills that are often undertrained in laboratory classes. Examples of such cognitive skills are: formulating hypothesis, judging the value of experimental results and designing experiments (Bennet & O'Neale 1998; Domin 1999). Would it be possible to develop an interactive 'design layer' around the webLM, allowing students to train their underexposed cognitive skills while designing their laboratory class and/or their experiments? The problems to solve in the laboratory class would in fact be the same problems students solved in the 'design layer'. So 'both' problem sets would share a lot of surface and structural features, increasing the probability of the (positive) transfer of skills (Novick 1988).

In addition, this ‘design layer‘ would contribute to alignment between intended learning outcomes and student activities (Biggs & Tang 2007).

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3. ExperD: web-based support for laboratory class workflow design and execution

Abstract

The design, use, and evaluation of a web-based experiment designer, ExperD, are described in this chapter. 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 supervisors see ExperD as a valuable addition to the laboratory class. Usage logs show that students used the tool throughout the entire laboratory class. Furthermore, ExperD proved to be a promising research tool for monitoring both student design activities as well as student actual lab work activities.

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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 & 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.

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:

- 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 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 supervisor. The supervisor provides feedback such as pointers to inconsistencies or inefficiencies.

In general, supervisors 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 (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, supervisors 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.

Supervisors 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.

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), the basic idea was to provide a web based tool that would support students in designing a workflow of experiments. Supervisor-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.

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. supervisors 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.

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 & 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'.

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, 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, ExperD should be integrated with the web based laboratory manual developed earlier (Kolk et al. 2011).

Table 1. ExperD design requirements.

Design requirement	How to determine whether the design requirement is met*.
r1. According to the students ExperD should be helpful a. in general	Student questionnaire questions/statements: 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	q3. "ExperD helped our group to work efficiently."
c. by giving them the overview	q4. "ExperD helped me to figure out what I could expect during the laboratory class." q5. "ExperD helped me to have the overview during the laboratory class."
d. by being easy to use	q6. "ExperD was easy to use." q7. "ExperD was self-explanatory." q8. "It was easy to distribute tasks using 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 supervisors.	Supervisor interviews
r4. Serve as a monitoring tool for design activities.	Supervisor interviews / Usage logging

* Evaluation questions use a five-point Likert scale (1 = disagree, 5 = agree) for response. We consider the design requirements to be met when at least 80% of the students rate an item as 4/ 5.

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 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 5). 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'.

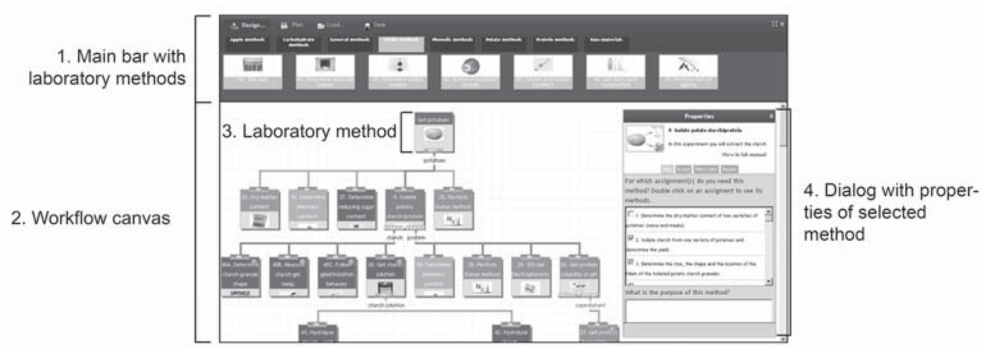

Figure 2. Overview of ExperD's user interface. Students design their experimental workflow by selecting experiments from the Main bar (1). The experiments (3) are added to the Workflow canvas (2) and students can connect them, or change their properties using a dialog (4)

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 (Figure 3) to the workflow. 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.

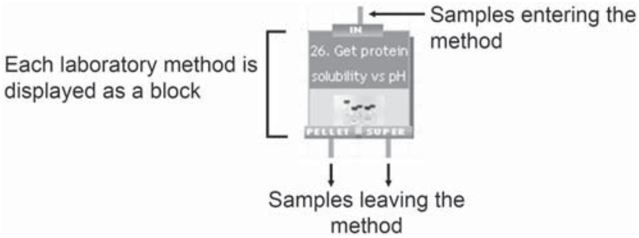

Figure 3. An experiment in ExperD is displayed as a block with ingoing and outgoing samples. For example: the experiment ‘Get protein solubility vs. pH’ has one ingoing sample ‘In’ and two outgoing samples ‘Pellet’ and ‘Supernatant’.

Next, students describe the sample in chemical/physical terms by selecting one or more properties from a list with properties (Figure 4). For example: Does the sample contain carbohydrates, fats, proteins; is the sample solid or liquid?

Figure 4. The properties dialog as configured in the course ‘Food Chemistry’. In this dialog students can view/edit the properties of the selected experiment.

To support the design process, 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, ExperD gives a warning message (Figure 5).

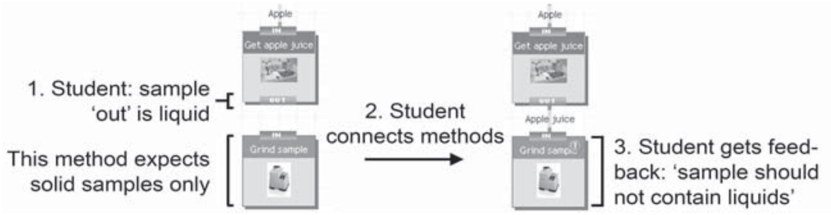

Figure 5. ExperD's feedback system is based on the student-defined properties of the samples going from one method to another.

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.

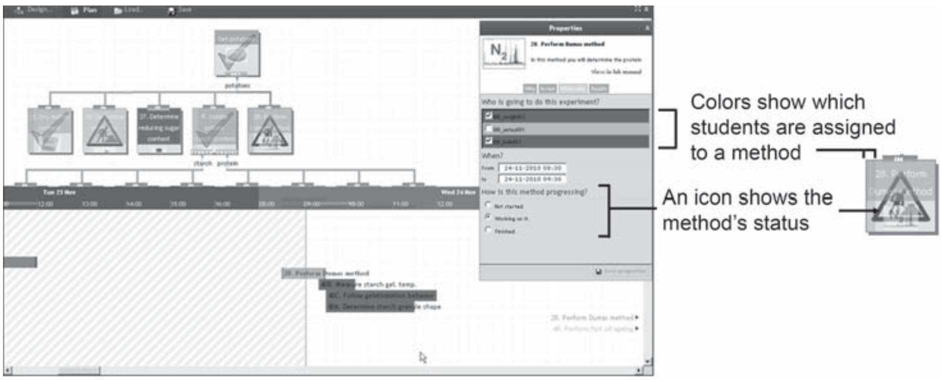

Figure 6. Overview of the time planning module with ExperD (introduced in 2011). Each experiment is in the workflow represented by a horizontal bar in the time planning. The position and the length of this bar represent the starting time and the duration of the experiment. The shaded area in the time 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'.

Students 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 ExperD can be linked (Figure 7) to a learning object in a web based laboratory manual (Kolk et al. 2011).

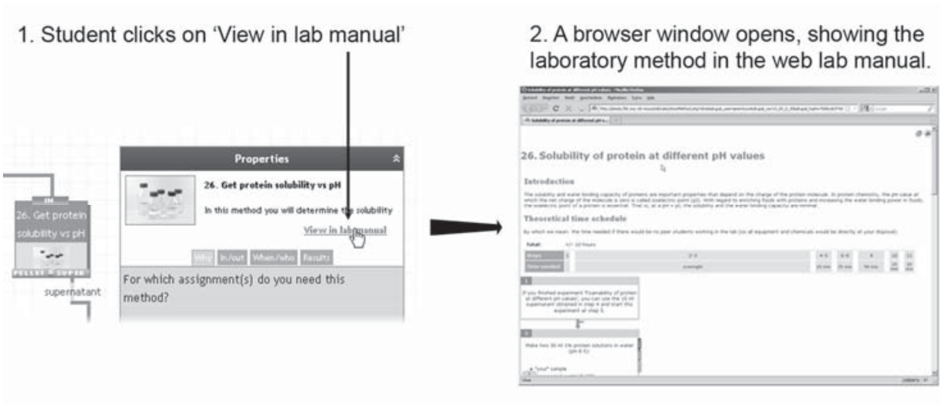

Figure 7. ExperD is linked to a web based laboratory manual. Students can view the online manual of a particular method by clicking on the 'View in lab manual' link in the properties dialog.

Two case studies

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 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 automated: any change to the workflow was instantly saved. In 2011 ExperD failed to provide feedback due to a technical problem. In both editions of the course, students designed a concept workflow on the first day of the laboratory class. The supervisors 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) ExperD was evaluated by the students by means of a questionnaire, which they had to fill in after the laboratory class ended. In 2009, supervisors 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 supervisors (n=6) were asked to comment on the conclusions of the 2009 interviews.

Collected data

The results of the questionnaire are listed in Table 2.

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 (%)*					% 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	ExperD was easy to use.	3	3	7	53	33	86
		0	7	11	59	22	81
q4	ExperD is self-explanatory.	2	5	25	58	11	69
		0	8	15	67	10	77
q5	ExperD helped our group to work efficiently.	0	3	3	58	36	94
		0	3	13	58	26	84
q6	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	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 ExperD's user interface.	3	3	19	41	34	75
		1	2	16	59	22	81

*) 1=disagree, 5=agree

The most important outcomes from the supervisor interviews from the 2009 case study were:

t1. The supervisors find ExperD a valuable addition to the laboratory class. It especially helped supervisors in discussions with students during the laboratory class, because both they and the students could easily indicate certain points in a standardized workflow.

t2. All groups did forget to include one or more experiments in their initial workflow designs.

t3. Some supervisors 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 supervisors did not recall that this occurred in previous years.

t4. 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".

t5. 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 supervisors of the course.

In Figure 8 the percentage of groups updating and using 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 ExperD usage and webLM usage are plotted per group. Between groups we found substantial differences in the intensity in which ExperD was used, the most active group generating 11 times as much updates as the least active group.

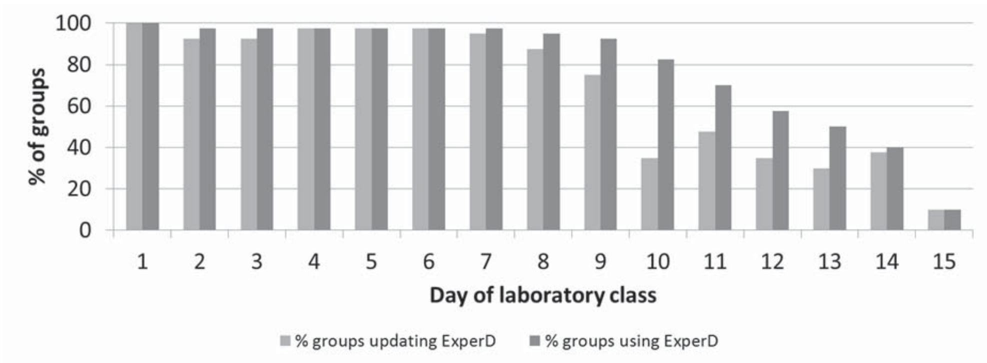

Figure 8. Percentage of groups updating and using their ExperD workflow at least once during the 2010 laboratory class. Groups making at least one change to their workflow are considered to be an 'updating' group for that day. Some groups did not update the workflow for one day, but did update it the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

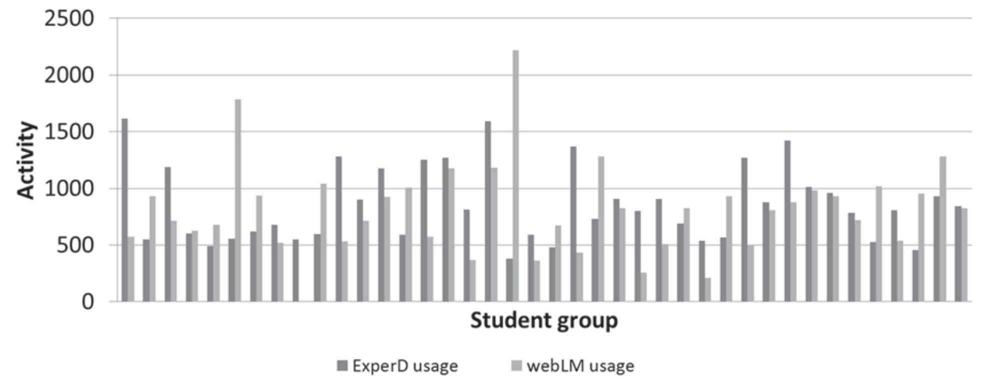

Figure 9. ExperD and web lab manual (webLM) usages per 2011 group. To obtain ExperD activity values, the number of laboratory methods changed in the workflow during the laboratory class was summed per group. WebLM usage was determined as described previously (Kolk et al. 2011). For one group, webLM usage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

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 ExperD.

Requirements 1 and 2: ExperD should be helpful for and used by students

Students found it useful to make a design with 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 ExperD to be available in other laboratory classes (q2). Students also indicate that 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 'ExperD gives students the overview' (requirement 2c): We have indications that 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 "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 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.).

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 ExperD and webLM intensively, and less 'computer minded' groups, which would avoid using both tools. Our results indicate that this is not the case.

Requirement 3: ExperD should be appreciated by supervisors

In general, the supervisors find ExperD a valuable addition to the laboratory class, as it helped them in their discussions with students (t1). However, supervisors were somewhat unpleasantly surprised by the extent to which 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.

Supervisors observed that all student groups did forget to include one or more experiments (t2). Letting 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.

Requirement 4: 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, supervisors 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 supervisors 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 supervisors to detect difficult or unclear assignments and other bottlenecks in a specific laboratory class.

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 supervisors 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 supervisors 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.

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4. Exploring the potential of smartphones and tablets for performance support in food chemistry laboratory classes

Abstract

Increasingly, mobile applications appear on the market that can support students in chemistry laboratory classes. In a multiple app supported laboratory, each of these applications covers one use-case. In practice, this leads to situations in which information is scattered over different screens and written materials. Such a multiple app supported laboratory will become awkward with the growth of the number of applications and use cases. In particular, using and switching between applications is likely to induce extraneous cognitive load that can easily be avoided.

The chapter describes the design of a prototype smartphone web app (LabBuddy) designed to support students in food chemistry laboratory classes. The chapter describes a case study (n=26) of the use of a LabBuddy prototype in such a laboratory class. Based on the evaluation of this case study, design requirements for LabBuddy were articulated. LabBuddy should work on HTML5 capable devices, independent of screen size, by having a responsive layout. In addition, LabBuddy should enable a student using LabBuddy to switch between devices without much effort. Finally, LabBuddy should offer an integrated representation of information.

Submitted

Introduction

Laboratory classes are essential for Food Chemistry education. We previously developed an electronic performance support system (EPSS), consisting of two web-based tools to support our food chemistry laboratory classes: A web-based experiment designer (ExperD) and a web laboratory manual (webLM) (Kolk et al. 2011). Students access these tools using desktop computers fixed to their lab benches. Much laboratory work, however, takes place on other locations: In various fume hoods and at various lab benches near equipment. This implies that there are many moments in time when students cannot access information provided by ExperD and webLM. As increasingly students bring their smartphone to the laboratory class, a 'mobilized version' of the current EPSS could support students during their work on those locations. The next section describes opportunities that we see for mobile devices in the laboratory class. We then describe a prototype of the mobilized version of the EPSS that we developed: LabBuddy. This tool was implemented and evaluated during the 2011/2012 edition of the course 'Food Chemistry' at Wageningen University. LabBuddy and its evaluation are discussed and based on this discussion design requirements for LabBuddy are made.

Two opportunities for smartphones in the laboratory

Of the eight week morning B.Sc. course 'Food Chemistry' (6 ECTS) at Wageningen University students spend three weeks in the laboratory. During this laboratory class, students should learn to design a workflow for their experimental tasks. Furthermore, they should learn to work in small groups (2-3 persons) and acquire experience with laboratory methods common for food chemistry. They also should learn to carry out these experiments efficiently, safely and meaningfully. The latter means that students should be aware of the theoretical background of the experiments during the laboratory class. Each group receives an agricultural raw material (e.g. soy, barley), mimics some steps of an industrial process (e.g. tofu preparation, beer brewing) and investigates major chemical changes during these steps. With regard to the 'Food Chemistry' laboratory class, a few years ago we established that:

1. Important cognitive skills, like designing workflows for experimental tasks, were undertrained.
2. Students often lacked the overview on their work while working in the laboratory.
3. The printed laboratory manual was a possible source of extraneous cognitive load because much information was implicit (e.g. what chemicals look like, hazards).
4. Supervisors (and students) spent relatively much time in the laboratory on relevant, but 'low level' questions like 'Where can I find…?' and 'What does … look like?'.

A web-based experiment designer (ExperD, Figure 1) has been designed, implemented and evaluated to meet points 1 and 2 (Kolk et al. 2012). Using this tool, students design a workflow of their experiments on a computer present on the lab bench. This workflow serves as a scaffold during laboratory work, as it shows students what experiment has to be performed when and – in the case of group work – by whom. Evaluation has shown that both students and supervisors consider ExperD to be an valuable addition to the laboratory class.

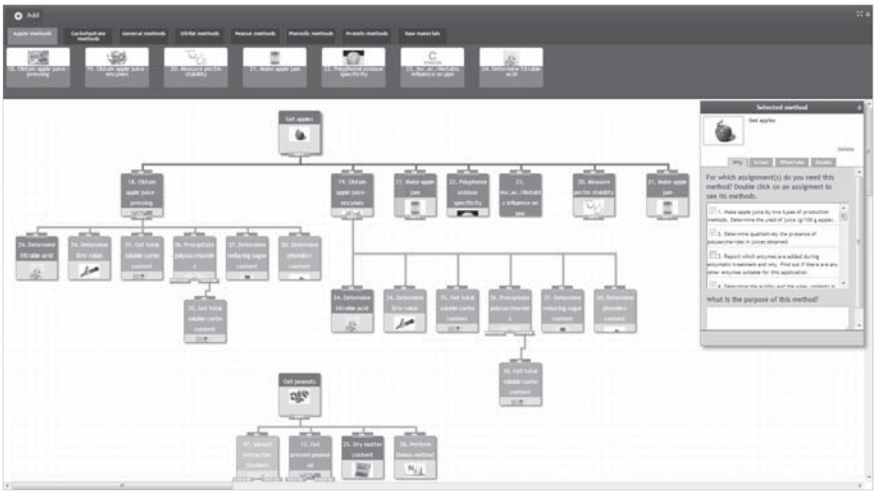

Figure 1. Screenshot of the experiment designer ExperD, in which students design a workflow of their experiments. Each 'block' represent one experiment and the lines connecting methods represent samples going from one experiment to the next.

Via the ExperD students can also access a web based laboratory manual (webLM), designed to meet points 3 and 4 (Kolk et al. 2011). The webLM gives students access to highly relevant, but 'low-level' information needed to meaningfully, correctly, efficiently and safely carrying out an experiment, such as the location of equipment and chemicals as well as procedural information (Figure 2). Evaluation has shown that both students and supervisors value the webLM (Kolk et al. 2011).

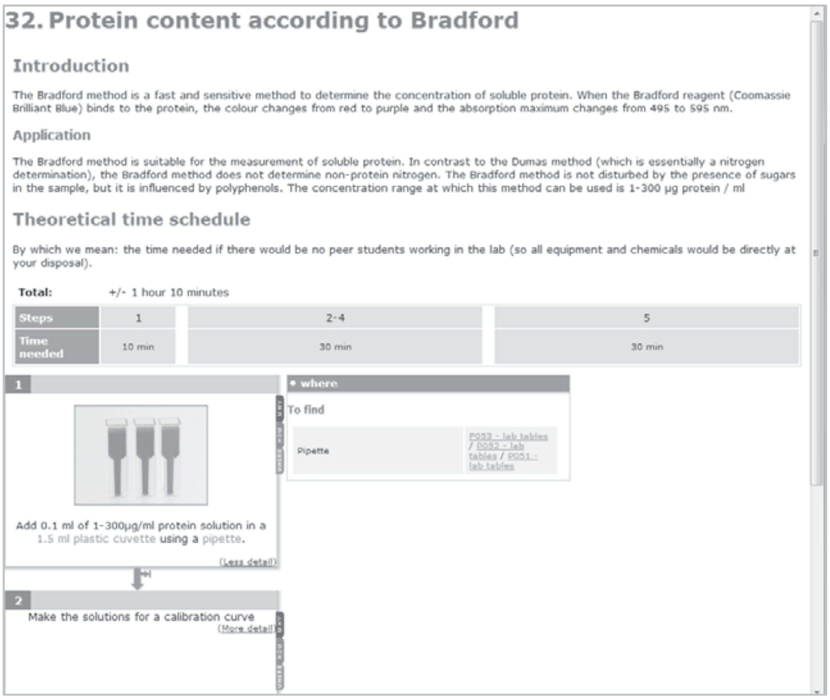

Figure 2. Typical screenshot of the web based laboratory manual (webLM)

1. Mobilizing our current laboratory class support system

Students access ExperD and webLM via a computer on their lab bench. However, many laboratory tasks should be (partly) carried out in the fume hood or on a lab bench near equipment. As there are no computers available, students have to switch to their printed laboratory manual when working at those locations. In 2011 about 30% of the B.Sc. students at our university owned a smartphone, and this number is increasing (EduSupport 2011). To facilitate these students, Wageningen University is preparing a Bring Your Own Device (BYOD) policy. This could lead to students bringing their smartphones – and tablets – to the laboratory in the near future. Yet, ExperD and webLM do not work well on those devices: Some features are not supported on touch screens and usability problems arise on devices with small screen sizes. The first opportunity is to bring the functionalities of those tools available on smartphones.

We do not envisage a laboratory class in which all students are obliged to use the mobilised support system on their smartphone. On the contrary, our strategy is to offer students a range of supportive tools on different media and offer them the choice.

2. Obtaining an integrated user experience

Increasingly, applications and uses of smartphones are being developed, which can support students during chemistry laboratory classes (Table 1). With the rapid growth of the number and variety of apps for support of laboratory work it seems likely that the resulting 'multiple app supported laboratory classes' become awkward from a cognitive load perspective.

Table 1. Smartphone applications which might be suitable for laboratory classes.

Application	Examples
Smart objects (Williams & Pence 2011)	QR codes on equipment and chemicals. When students scan these using their smartphone, they will get instruction movies, MSDS sheets, etc.
Calculator applications (Williams et al. 2011)	Biochemistry Lab Suite[i], Solution Calculator[ii]
Log book applications	eLogger[iii], LabArchives[iv]
Delivery of chemical facts and figures (Williams et al. 2011)	ChemSpider mobile website[v], Promega App[vi], Protocolpedia[vii], Lab Unit Converter[viii]
Digitization of measurements	A smartphone spectrophotometer; a pH meter connected to a smartphone[ix] (Chang 2012).

According to cognitive load theory people have a limited 'working memory'. If a task requires learners to have too many chunks of information in their working memory simultaneously, their working memory becomes ‘overloaded’. In such an overloaded situation student problem solving and learning are hampered (Kirschner 2002; Sweller et al. 1998). Mayer and co-workers have articulated design principles for user interfaces to avoid extraneous cognitive load (R. C. Clark & Mayer 2007; Mayer et al. 2001; Mayer & Moreno 2003). Students encounter various user interfaces in the multiple app supported laboratory: The laboratory manual, the user interfaces of applications on their smartphones and computers, the user interfaces of the various laboratory apparatus, etc. We consider these user interfaces to be part of one overarching user interface, the ‘laboratory class user interface’ (Figure 3).

Figure 3. Part of the laboratory class user interface.

Next, we hypothesize that the design principles for ‘normal’ user interfaces also apply to this laboratory class user interface. If this is the case, some of these design principles are being violated by the laboratory class user interface in a multiple app supported laboratory. This can be illustrated using a fictitious, but realistic, scenario in which a student is carrying out a SDS electrophoresis. This student reads the instructions for preparing a SDS-gel from the printed laboratory manual: ‘Add 30µl β-mercaptoethanol buffer’. Because he remembers that there was an issue with β-mercaptoethanol, he decides to search for safety information using the ChemSpider mobile web application on his smartphone. After some tapping, he ends up on the mobile Wikipedia page of 2-mercaptoethanol and finds the safety information there. During the next step of the experiment, 'Boil for 4 minutes', the student uses a countdown timer application on his smartphone. Reading 'Add sample to SDS-gel' he then wonders whether he has signed up for the SDS gel electrophorese apparatus. To check this, he opens an online subscription list on one of the computers in the laboratory class.

Based on principles from literature (R. C. Clark & Mayer 2007; Mayer & Moreno 2003; Sweller et al. 1998; Mayer et al. 2001), we conclude that it is likely that the student in above scenario has to deal with extraneous cognitive load, caused by

- the absence of spatial contiguity between information.
- the presence of non-essential information, e.g. the boiling point of β-mercaptoethanol while searching for safety information on β-mercaptoethanol.
- the different – and for students unfamiliar – interactions with different user interface elements.
- the need to remember information while interacting with the user interface, e.g. remembering the term 'β-mercaptoethanol' read in the laboratory manual while searching for safety information and remembering this safety information while carrying out the laboratory method step.

Because of this, it is to be expected that students are underperforming during that particular laboratory class. For the sake of argument the above scenario was deliberately chosen to be worst case. There are also applications on the market which cover multiple use cases, e.g. the 'Biochemistry Lab Suite' application (see Table 1). Students who use applications like these will most likely suffer less from extraneous cognitive load. So, there is a continuum. At one side there is a situation in which students have 'piecemeal interaction', namely "the experience of using different applications, often with very different user interface styles, to interact with and control the different devices and services with which one interacts" (Newman et al. 2008). At the other side there is "the situation in which students have an integrated user experience: the experience of having a convenient, seamless access to a variety of resources inside and outside the laboratory" (Newman et al. 2008).

Design goals

During this research a design-oriented research approach was taken (Österle et al. 2010). For design of digital learning support and resources, this approach entails the following research questions:

1. "what are, in a specific real university context, goals that make sense and why,
2. how can these goals be articulated in terms of measurable quantities,
3. is it possible to achieve these goals,
4. if so, how?" (Hartog et al. 2010)

To a large extent, this type of research involves constraint exploration efforts (Jonassen 2008; Gross 1985). Based on the introduction section above, it can be concluded that there are two sensible design goals to achieve in our laboratory education. Firstly, to 'mobilize' our current EPSS, so that it supports students on locations in the laboratory where they do not have access to personal computers. Secondly, to offer an 'integrated user experience', in which students working in the laboratory do not have to switch between different information resources. The aim of this research was to explore the constraints of a tool that meets these goals. This exploration took place by designing, implementing and evaluating a prototype tool: 'LabBuddy'.

Design and realization of LabBuddy prototype

The majority of nowadays' smartphones runs on different platforms, e.g. iOS (Apple), Android (Google), BlackBerry OS (BlackBerry) or Windows Phone (Microsoft). Applications developed for one platform do not work on other platforms. Because it would exceed our budget to develop different applications for all platforms, we had to look for alternatives. What most smartphones have in common is that they come with a web browser. So, if LabBuddy were to be a 'web app', an application running in the web browser using HTML/CSS/JavaScript, one version of LabBuddy would work on all platforms.

To determine a list with desired functionalities for LabBuddy, B.Sc./M.Sc. thesis students, Ph.D. students, assistant professors/post-docs and technical staff of our Laboratory participated in a group discussion. Before the group discussion one of the authors gave a presentation about ExperD, webLM and the possible functionalities of LabBuddy. For each functionality, participants (n=44) were asked to give their opinion on the usefulness of the functionality for the laboratory classes. The results of this questionnaire are listed in Table 2.

Based on the estimated time/costs and on the estimated ease with which functionalities could be realised, the following functionalities were selected for LabBuddy prototype:

- list of scheduled laboratory methods;
- laboratory method texts;
- integrated countdown timers in laboratory method text;
- adding text notes to laboratory method steps;
- adding files to laboratory method steps, e.g. Excel files with results;

A prototype of LabBuddy was realized using HTML5, CSS and JavaScript. This prototype receives its laboratory method data from the webLM database and connects to the ExperD to obtain the list of laboratory methods of the student using LabBuddy. The prototype was frequently tested on different smartphones. LabBuddy was also tested in Mozilla Firefox and Google Chrome on the pc. An overview of the realized functionalities is given in Figures 4 and 5. Figure 4 shows the list of laboratory methods in the ExperD scheme of the group to which the student belongs (left screenshot). The ExperD offers the possibility to assign laboratory methods to group members, which is reflected in LabBuddy's user interface. Also, the planning information is shown in LabBuddy. From this list of methods students have access to individual laboratory methods. The right screenshot in Figure 4 shows an example of an equipment/chemical information page. On such a page students can find a picture of the equipment/chemical, its location and video tutorials.

Figure 5 shows a laboratory method in LabBuddy. Initially, a short description is given of all method steps.

Table 2. Functionalities of LabBuddy and the opinion of the group discussion participants (n=44) on the usefulness (perceived usefulness, PU) for laboratory classes. This PU is expressed as the percentage of participants rating the functionality with 4 or 5 on a 5-point usefulness scale. The functionalities are ordered by the PU.

	The student should be able to:	PU %4/5
1.	View a list of laboratory methods present in the research strategy designed in ExperD	89
2.	Add photos/videos to laboratory method steps.	84
3.	View scheduling info (e.g. when equipment is booked) of laboratory methods.	84
4.	View a 'shopping list' containing all chemicals / small equipment of a laboratory method.	84
5.	View a list of active countdown timers in laboratory method steps (see section 7).	82
6.	View laboratory method texts with locations of equipment, hazard sheets, instruction movies and theoretical background information.	79
7.	Use integrated countdown timers in laboratory method text (see Figure 5).	77
8.	Add text notes to laboratory method steps.	77
9.	Book equipment.	70
10.	Add files to laboratory method steps, e.g. Excel files with results.	56
11.	View all user activities within LabBuddy, which could serve as a logbook. E.g. Tuesday 15 May 9:00u opened method 'SDS-electrophoresis' 9:15u text note 'Added 34µl β-mercaptoethanol' (step 3).	42
12.	View and add practical advice with respect to laboratory method steps. For example 'add salt quickly', to a method step in which salt is being added. This advice is directly visible to other users carrying out that method step.	40
13.	Add sketches to laboratory method steps.	27
14.	Add audio notes to laboratory method steps.	26
15.	Use smart calculators in laboratory method steps, e.g. buffer calculation, calibration curve calculations and adaptive text (e.g. 'Add 5 ml NaOH solution' becomes 'Add 2.5ml NaOH solution' when the student indicates that he/she uses a two times more concentrated NaOH solution).	12

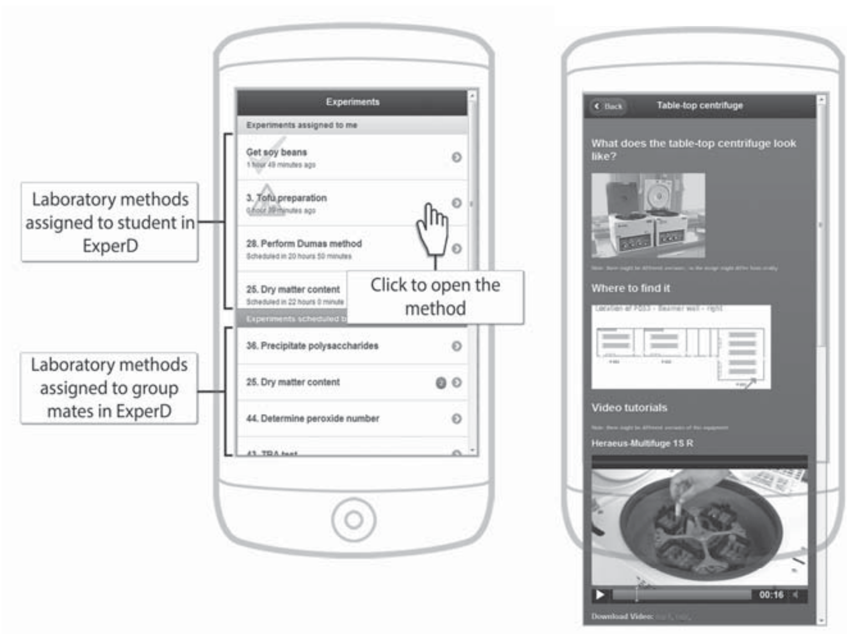

Figure 4. Left: The list of laboratory methods which are in the student group's ExperD workflow. Right: Example of an equipment/chemical information page.

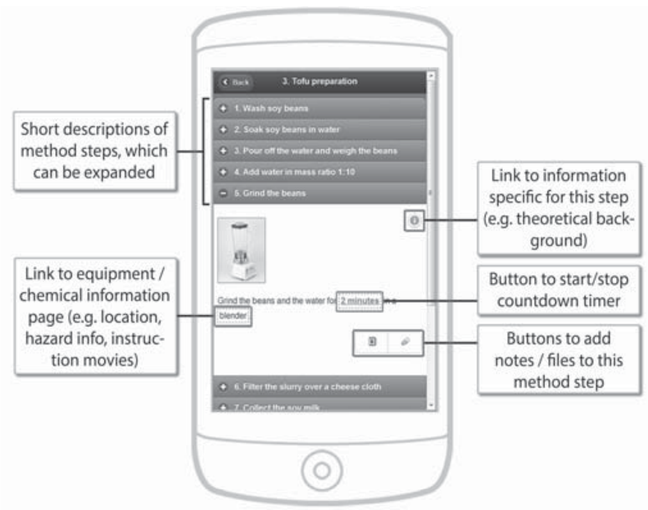

Figure 5. Presentation of laboratory method in the LabBuddy prototype.

These method steps unfold when clicked. In this detailed view students can add text notes and files to the method steps. They can also access theoretical background information of the method steps and manage inline count down timers. Finally, they can access information specific for equipment/chemicals used in the step.

Pilot: LabBuddy prototype in the laboratory class

The prototype of LabBuddy was introduced to students (n=105) in the November/December 2011 edition of the laboratory class 'Food Chemistry'. During the whole laboratory class, student groups had access to an internet-connected pc on their lab bench. Students with smartphones could access the internet via WiFi. On the first day of the laboratory class student groups designed a workflow of their laboratory class using the ExperD. From day 2 until 15 they were carrying out the experiments and writing their report. During these experiments, students could access the ExperD and webLM using their lab bench desktop pc, and use the prototype of LabBuddy on their smartphone or their group pc. Students were free to use the webLM and ExperD on the lab bench desktop, LabBuddy on their smartphone and printed laboratory manual. They could also freely switch between these information resources. The first author discussed LabBuddy with students while they were using it. During these discussions some minor bugs where identified and repaired and additional requirements were explored.

After the laboratory class ended, students received a questionnaire. A subgroup (n=26) indicated to have a smartphone and to have tried LabBuddy. The results of the questionnaire are listed in Table 3. A minority of 26 students tried the LabBuddy prototype, of which 7 students kept on using the tool until the end of the laboratory class

Table 3 Questionnaire results of students having a Mobile internet access device (n=26). Students could rate the questions on a 1-5 scale (1=Strongly disagree, 5=Strongly agree). The results are split in two groups: those students who used the prototype of LabBuddy during the whole laboratory class (the users, n=7) and those students who stopped using it (the dropout-users, n=19). The '#4/5' column shows the number of students rating the question with either a 4 or 5.

	Question	#4/5
Users (n=7)	1. I would like to have such an application in other laboratory classes as well.	7
	2. LabBuddy is easy to use.	7
	3. LabBuddy made the laboratory class more interesting.	3
	4. The layout of LabBuddy was clear.	7
	5. Having instruction movies of equipment is a useful feature of LabBuddy.	5
	6. The possibility of adding notes/attachment to method steps is a useful feature of LabBuddy.	5
	7. Having countdown timers in method steps is a useful feature of LabBuddy.	7
	8. Having the locations of equipment is a useful feature of LabBuddy.	6
	9. I used LabBuddy for reading the laboratory method steps:	
	a. when working at our group's lab bench	7
	b. when working in the fume hood	4
	c. when working at a different location, e.g. near equipment	7
	10. LabBuddy was a full replacement for the written laboratory manual.	5
	11. LabBuddy was a full replacement for the electronic laboratory manual on the pc.	5
	12. What is your overall rating of this LabBuddy?	7
	Question	**#4/5**
Dropout-users (n=19)	13. Why did you not use / stopped using LabBuddy? (more than one answer possible)	
	a. Because it is inconvenient to use a phone during lab work.	11
	b. Because LabBuddy application's features were not useful for me.	6
	c. The webLM and ExperD and printed laboratory manual were sufficient	5
	d. Because I was afraid that my phone would be damaged (e.g. by chemicals).	3
	e. Because LabBuddy application was too difficult to use.	0

Comments on the data

During the pilot experiment 7 out of 26 students (further referred to as 'users') continued using the LabBuddy prototype and 19 students stopped using it ('drop-out users'). The responses of the 7 users to important questions in the questionnaire, such as 'I would like to have such an application in other laboratory classes' (question 1), 'LabBuddy is easy to use' and 'What is your overall rating of this LabBuddy' (question 12), were unambiguously positive. These results also indicate an appreciation for the functionalities of LabBuddy (question 5-8). The majority of the users sees LabBuddy as a full replacement for the printed laboratory manual and webLM (questions 10-11). This is especially the case when working at lab benches (questions 9a and 9c). Not all students used LabBuddy while working in the fume hood, which can be expected because of the often harsh chemicals used there (question 9b).

With regard to the drop-out users, we first would like to re-emphasize that we do not envisage a laboratory class in which all students are using LabBuddy on their smartphone, but rather a laboratory class in which students can choose and switch between modes of delivery. In accordance with (Kukulska-Hulme et al. 2011) we think that learners who use smartphones in educational settings are in the minority *at present time*, but that this will change in the near future. Smartphones are relatively new, and might not yet be an integral part of the everyday lives of all our students. This might partially explain why 11 of the drop out users found it inconvenient to use a smartphone during laboratory work. Another component of the explanation might be that the level of integration of the user experience of LabBuddy currently still is insufficient. Indeed we are not yet satisfied with the level of integrated representation of information from various resources in the prototype as depicted in Figure 5 and Table 2. Method step-specific and equipment-specific information is not shown on the same screen as the laboratory method. Thus, a student who e.g. wants to work safely with 'β-mercaptoethanol buffer' still has to switch between two screens to get all information. A third component of the explanation for the perceived inconvenience of using LabBuddy can be that our current laboratory was not 'smartphone-friendly' enough. There were, for example, no smartphone holders or stands present in the laboratory. So, students had to have their smartphones lay flat on the lab benches while experimenting, which might be awkward from an ergonomic perspective. The number of dropout-users giving as a reason that their phone might be damaged (n=3) was lower than we expected. We thought on beforehand that 'wet' Food Chemistry laboratory work would discourage many students from using their (expensive) smartphones.

Design requirements LabBuddy

Based on the above considerations we articulate the following list of design requirements for LabBuddy.

LabBuddy should work on HTML5 capable devices, independent of screen size, by having a responsive layout. Of course, introducing tools as the LabBuddy web app in education is a matter of costs and benefits. As the web lab manual (webLM) is valued and used by virtually all of our students at their lab bench computers (Kolk et al. 2011), a sensible design requirement for LabBuddy would be that it can be used on those computers as well. LabBuddy would then work on all HTML5 capable pcs, tablets, tablets, independent of the operation system or brand. Technically this is feasible, as the newest web technologies (HTML5 / CSS3) allow for so-called 'responsive' (Marcotte 2010) layouts, layouts that automatically adjust themselves when presented on different screen sizes. In practice this would mean that LabBuddy replaces webLM.

LabBuddy should enable a student using LabBuddy to switch between devices without much effort. Experiments can be carried out at different locations in the laboratory: Some in the fume hood, some near a piece of equipment and some at the lab bench. A student who performed an experiment in e.g. the fume hood using LabBuddy on his smartphone, might want to continue working at the lab bench using the computer. S/he might also want to copy-paste results from LabBuddy to a word processor or spread sheet on the pc. This comes with an design requirement for LabBuddy: students should be able to switch from working with LabBuddy on their pc to working with LabBuddy on their smartphone or tablet (and vice versa) without much effort. Furthermore, LabBuddy shows a personalized list of experiments assigned to the student in ExperD (Figure 4). On shared devices – like the lab bench pc – this creates a problem, as multiple students can use the same LabBuddy. Hence an addition to the design requirement is that it should allow for switching between students on shared devices without much effort.

LabBuddy should offer an integrated representation of information. In the laboratory students deal with the 'laboratory class user interface', composed of the user interfaces of computer programs, smartphone apps, equipment, bottles, laboratory manuals, etc. As this might lead to the cognitively awkward 'piecemeal interaction' (Newman et al. 2008), LabBuddy should offer an integrated user experience. This experience might be achieved by an integrated representation of information (Figure 6) in LabBuddy's future user interface.

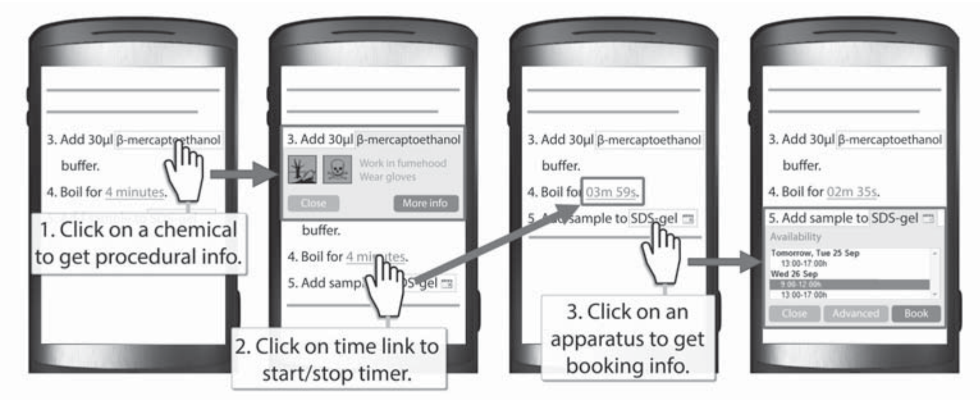

Figure 6. Three examples of an integrated representation of information from various resources in LabBuddy.

One aspect of this design requirement is that LabBuddy should communicate with ExperD, in which students design and update their research strategy. Only experiments present in this research strategy should be present in LabBuddy and information related to the experiments (e.g. booking information, notes, results) should be synchronized between ExperD and LabBuddy. An overview of LabBuddy-ExperD system is given in Figure 7.

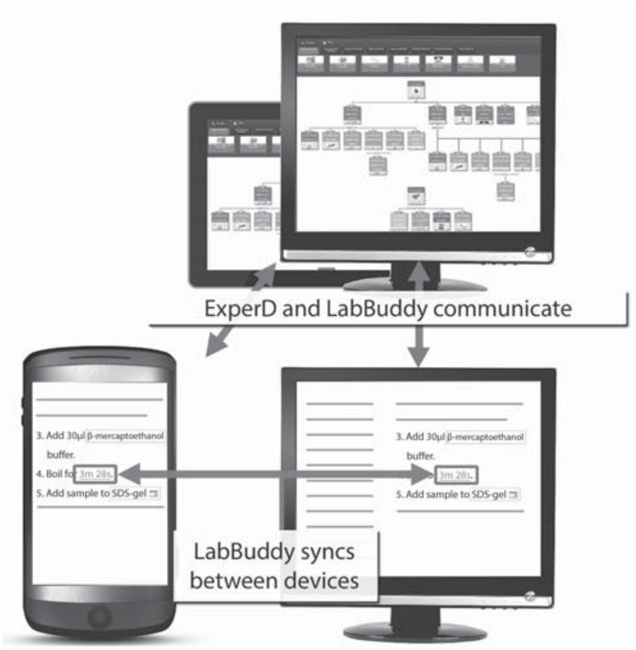

Figure 7. Overview of LabBuddy and ExperD. Changes made in LabBuddy are synchronized between LabBuddy's and between ExperD and LabBuddy (and vice versa)

Conclusions

The aim of this research was to explore and articulate the constraints of a web app (LabBuddy). Based on our findings, the following design requirements for LabBuddy were articulated. LabBuddy should work on HTML5 capable devices, independent of screen size, by having a responsive layout. In addition, LabBuddy should enable a student using LabBuddy to switch between devices without much effort. Finally, LabBuddy should offer an integrated representation of information.

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[vi] https://play.google.com/store/apps/details?id=com.promega
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5. Design and evaluation of a computer assisted learning scenario enabling supervisors to manage an inquiry M.Sc. level food technology laboratory class

Abstract

Inquiry laboratory classes are suitable to acquire academic skills, such as designing research strategies and independently carrying out research. Due to their open nature, guided inquiry laboratory classes can be more difficult to manage than laboratory classes of a relatively closed nature, such as expository or verification-based laboratory classes. To cope with the organisational challenges of a guided inquiry M.Sc.-level food technology laboratory class, we developed a computer assisted learning scenario. Central in this learning scenario is a web based experiment design tool ExperD, which formalises the communication about research strategies, handles the booking of apparatuses and enables monitoring of students' progress. From the evaluation with 142 students and 10 supervisors we conclude that the learning scenario was successful. Based on the evaluation we formulate recommendations to improve the learning scenario as well as suggestions for a mobile webpage that enables teachers to keep track of student group progress in the laboratory.

Submitted

Introduction

Domin (1999) described a taxonomy of laboratory classes. In so-called 'inquiry' laboratory classes, students create procedures themselves and move from specific observations to broader generalizations and theories. In addition, teachers do not know the outcomes of experiments beforehand (Domin 1999; Domin 2007). The open nature of inquiry laboratory classes might discourage teachers from incorporating them in the curriculum. For example, it has been reported that inquiry type laboratory classes cause teachers to experience a sense of chaos (Weaver et al. 2008), in which they fear a loss of control (Deters 2005; Montes & Rockley 2002; Schoffstall & Gaddis 2007). Also, the organization of an inquiry type laboratory class can be a challenge for teachers (Domin 1999; Johnstone & Al-Shuaili 2001).

The set-up of the laboratory class of the M.Sc. course 'Food Ingredient Functionality' at Wageningen University can be characterized as 'supported inquiry'. So, it is an inquiry laboratory class, but students are not 'minimally guided' (Kirschner et al. 2006), as they receive support from supervisors during their inquiries in the laboratory. The open-end nature of this laboratory class poses organizational and educational challenges. This manuscript describes a computer assisted learning scenario designed to overcome some of these challenges.

Organizational context

The 8-week M.Sc. morning course 'Food Ingredient Functionality' (6 ECTS) at Wageningen University, The Netherlands is organised by the Laboratory of Food Chemistry, in cooperation with the Food Physics Group. During the course, students study the relationships between the chemical/physicochemical structure of food ingredients and their techno-functional (e.g. gelling) properties, and to a lesser extent their bio-functional (e.g. bio-activity) and sensory properties. The course, which attracts between 100 and 150 students each year, can be divided into four parts: lectures and tutorials (week 1-3), a laboratory class (week 4-6), a self-study week (week 7) and an exam (week 8).

During the laboratory class, each student group of ~7 students works with a particular class of food ingredients, e.g. polysaccharides comprising different types of alginates and pectins. The student groups receive an assignment consisting of three parts. For the first part, groups should design a research strategy to identify 5 different food ingredients (e.g. 5 different polysaccharides), which have been provided to the group as encoded samples. The rationale for the first part is to motivate students by offering them a problem to solve (Keller 1987). In order to solve the problem, students have to study the theory behind the ingredients and apparatuses. This part of the assignment is not realistic, in the sense that students cannot expect to get such an assignment when they will later work as graduates in industry. For the second part of the assignment, groups should design a research strategy to demonstrate the influence of various conditions on a model system made with a selection of the food ingredients identified during the first part. For example: the influence of both slow- and fast-release calcium on the formation of alginate gels. For the third part, groups should design a research strategy to create a model system of at least 2 ingredients from different ingredient categories. For example: inhibiting drainage of a protein-stabilized foam by adding alginate to the continuous water phase). The second and third part of the assignment are typical tasks graduates could get when they have a research or product development job in food industry.

One important learning objective of the laboratory class is that students should learn to make informed decisions on experiments. Student groups receive a laboratory manual with 26 experiments fundamental to the fields of food chemistry and food physics. The vast majority of these experiments involves the use of sophisticated apparatuses, e.g. MALDI-TOF MS, HPAEC and texture analysers. Student groups can also perform experiments that they find in literature. Student groups should decide which experiments they want to conduct. Subsequently, they should discuss these decisions with their supervisors before the laboratory work starts. If needed, they can adapt their strategy during the laboratory class in consultation with their supervisors. At the end of the laboratory class students present their results to the other students and the supervisors during a symposium. Students receive a mark based on the quality of their work and the contents of the presentation.

Challenges

The Food Ingredient Functionality laboratory class as described above poses two challenges:

The first challenge is to warrant the quality of the research strategies student groups design and conduct during the laboratory class. Most students come unprepared to the laboratory class, having mediocre theoretical background knowledge at best, and often no clue of what to expect. Until the 2012/2013 edition of the course, student groups designed their research strategy during the first day of the laboratory class. The communication between groups and supervisors about this research strategy was not formalised. This confronted supervisors with different formats in which students presented their strategy to them: From (lengthy) textual descriptions to tabular designs and self-made graphical representations. During the laboratory class students could adjust their research strategy when necessary. Because students often did not inform the supervisor about these changes, it was difficult for supervisors to monitor the groups and to redirect a group when the quality of the research was at risk.

The second challenge is to give student groups the freedom to plan their experiments without the supervisors losing control and without risking overbooking of apparatuses. This is the major reason why the student group size is rather large (~7 students), although supervisors are aware of the pitfalls of large student groups ('free-rider' problem and the problem of individual students performing insufficient number of experiments). Prior to the 2010/2011 edition of the course, each group could use apparatuses within certain time slots, which were booked for them by supervisors. In this controlled set-up, many groups had the tendency to perform all experiments with all samples ('just in case'). According to the supervisors, very few informed decisions on the use of apparatuses were made prior to the experiments. During the 2010/2011 edition of the course students received the freedom to book their apparatuses. Paper sign-up lists were provided and groups could subscribe (or unsubscribe) during the whole laboratory class. Supervisors hoped that this freedom would trigger students to make more informed decisions, as they could not just use the apparatuses booked for them by the supervisors. However, with 105 students able to book – and unbook – 26 different apparatuses at any time of the laboratory class, sign up lists quickly became unusable because of the many changes students made. Moreover, some conflicts arose between groups, because some groups were booking apparatuses for a number of consecutive days. In addition, it became more difficult for supervisors to know which experiments students were conducting at a certain moment. In the 2011/2012 edition of the course (115 students) a prototype of an electronic booking system was introduced, which proved to be promising.

Theoretical building blocks

It is important that students have pre-lab activities (Johnstone & Al-Shuaili 2001) in order to “prepare the mind to recognize the expected changes, to be surprised when something different occurs, to have the requisite theory ‘at the top of the head’ to guide what is going to be experienced.” (Johnstone 1997). Meester and Kirschner propose to include pre-lab assignments to “to solve problems, to use knowledge and skills in unfamiliar situations, and to design (simple) experiments to test hypotheses.” (Meester & Kirschner 1995). Yet, the transfer of skills learned during pre-lab assignments, completed in a computer room, to the ‘real’ food chemistry laboratory can be problematic as students “do not put in practice what they have learned during the [pre-lab] assignments” (Diederen et al. 2006).

Biggs advocates ‘constructive alignment’ in educational practices, which is “to set up a learning environment that supports the learning activities appropriate to achieving the desired learning outcomes” (Biggs 2008). In an aligned laboratory class, there is no escape for students having different goals than the learning outcomes of the laboratory class: they can only reach their goals by reaching the laboratory class outcomes (Biggs & Tang 2007).

Another notion is that of scaffolding. Chemistry laboratory work tends to be demanding from a cognitive load perspective (Johnstone & Letton 1990; Johnstone et al. 1994; Kolk et al. 2011). In such a demanding environment, students can be helped by ‘problemizing’ aspects they might otherwise overlook (Reiser 2002). Additionally, tools for representing and manipulating information in a task – in this case: the task of designing and carrying out a research strategy – can be used as a lever to shape the way students think about that task (Reiser 2002).

ExperD, a web-based tool described elsewhere (Kolk et al. 2012), requires students to represent their research strategy as a workflow of experiments. Questions can be added to ExperD, which should be answered by students while designing their research strategy. With these questions, students can be prompted to consider aspects of the research strategy they might otherwise overlook, for example: informed decisions on experiments. ExperD was highly valued by both students and supervisors (Kolk et al. 2012). Finally, although the student group’s ability to make informed decisions on experiments was a learning objective of the laboratory class, the term 'informed decision on experiment' was not defined in previous years. The working definition is now articulated as in Table 1.

Table 1 Working definition of informed decisions on experiments within Food Chemistry laboratory classes.

Definition	Examples
An informed decision on an experiment is a decision in which a student consciously chooses to conduct the experiment with a certain sample, based on	
1. the research question;	"What is the protein content of this sample?"
2. knowledge on the available experiments to perform this operation;	"The protein content can be determined by the experiments according to Dumas, Bradford, …"
3. input constraints: required sample properties and perturbing sample properties;	"Protein content according to Bradford requires a soluble sample and gives unreliable results when the sample contains polyphenols."
4. precision constraints;	"Protein content according to Dumas involves a correction with a nitrogen conversion factor, which has an error margin of…"
5. time constraints;	"In this laboratory class, protein content according to Dumas needs to be carried out overnight…"
6. money constraints;	"… and costs €3 per sample."

The learning scenario

We designed a learning scenario to overcome the challenges mentioned in the introduction. A timetable with student and supervisor activities during the learning scenario is given in Table 2. During the first two weeks of the learning scenario (week 2 and 3 in Table 2) students follow lectures. During these lectures they learn the theory needed in the learning scenario.

Table 2. Student and supervisor activities during the learning scenario. The learning scenario is executed from the Monday of week 2 of the course until the Monday of week 6. Items between brackets are not part of the learning scenario.

	Week of course:	(1)	2	3	4	5	6
Student groups	(Follow lectures)						(Analysis of results, preparing presentation, symposium)
	Design / update research strategy						
	Book apparatuses						
	Perform experiments						
Super-visors	Give feedback on research strategy						(Support students in preparing presentation)
	Supervise laboratory class						

Student group activities

At the first day of the scenario (Monday of week 2) groups receive a letter from a fictitious food ingredient company, ‘GrupVinck’. This letter contains an assignment, as described in the introduction. The GrupVinck letter emphasizes that the quality as well as the costs of the proposed research strategy should be considered. In weeks 2 and 3, student groups design their initial strategy. To facilitate the design process, students have access to ExperD, which is linked to a web-based laboratory manual (Kolk et al. 2011). ExperD enables students to create an annotated workflow of experiments (Figure 1).

ExperD enables real-time collaborative workflow design, as different group members can use the tool simultaneously on different computers to design the same workflow. Student groups can also keep track of their progress in executing the workflow and divide tasks amongst group members. For each experiment that a student group adds to the workflow, ExperD asks ‘informed decision questions’. For example: “On which chemical/physicochemical characteristic does this experiment distinguish between your samples?”, “Do your samples require pre-treatment before the actual measurement takes place (see lab manual)? If so, why?” and “Which step/steps in the experiment will be problematic and/or time consuming? Why?". In case of questions or problems, students can contact supervisors by e-mail or ask questions after one of the lectures given in that period.

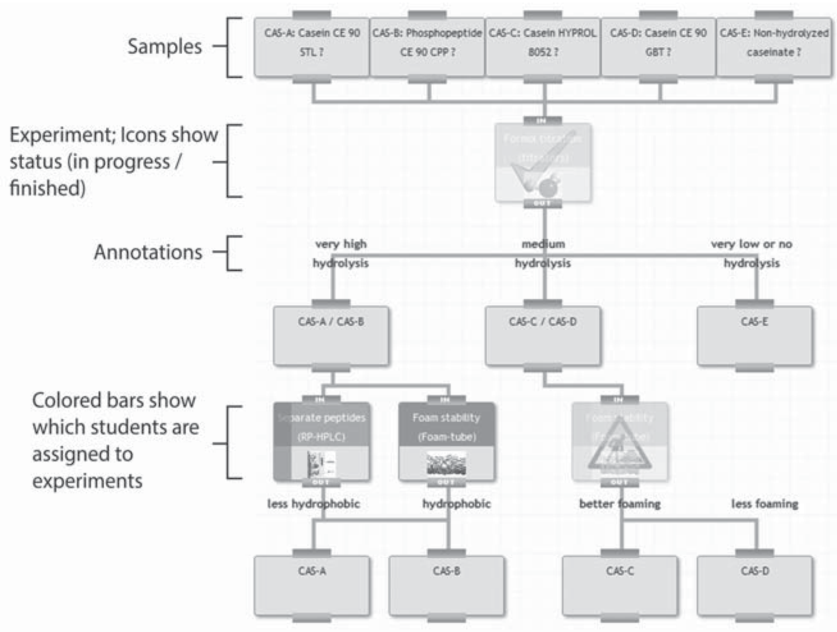


Figure 1. Excerpt of a workflow (decision tree). Samples are depicted as gray boxes, experiments as coloured ones. Student groups can annotate the workflow e.g. with their expectations on the results from the experiments. They can also keep track of their progress in executing the workflow by changing the status of experiments to 'in progress' or ' finished' and divide tasks amongst group members.

As most experiments require the use of sophisticated apparatuses (e.g. HPLC, HPAEC, MALDI-TOF MS, viscosity meters), student groups can book this apparatuses using ExperD's booking system from the midst of week 3. Access to the booking functionality is initially blocked, because we do not want student groups to focus too much on booking. Instead, they should focus on the design of a good strategy. For each apparatus a number of planning parameters has been defined in ExperD: The number of apparatus being available, the dates and times they are available, the time needed per measurement, the maximum number of samples a group is allowed to measure per day and the maximum number of samples a group is allowed to measure during the complete laboratory class. A student group has to enter the number of samples they want to measure and drag the booking to the desired date/time (Figure 2).

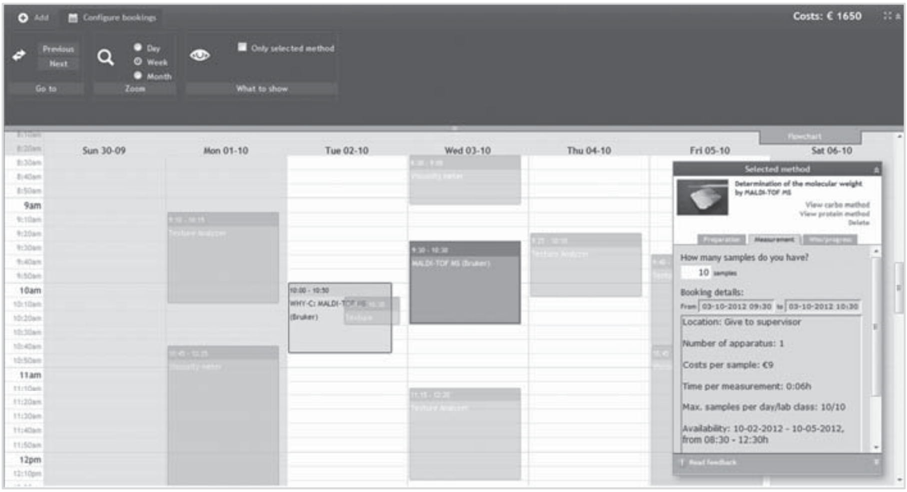


Figure 2. Screenshot of the booking system. In this example the 'MALDI-TOF MS' is being booked. Students can change the number of samples in the 'Selected method' dialog. Each apparatus has a costs per sample. The total cost of the research strategy is shown at the top-right.

Using the planning parameters, ExperD then uses a booking algorithm to determine whether the student group can use the apparatus on the desired date/time to process the indicated number of samples. If this is not the case – e.g. because the apparatus is already booked or because the students want to process too many samples – ExperD gives feedback and proposes an alternative timeslot The rationale for defining the planning parameters is twofold. Firstly, it is to trigger students to think about what samples they really need to process to complete their research assignment (instead of blindly processing all samples). Secondly, as the apparatuses are mainly used for research of the Laboratory of Food Chemistry and the Food Physics Group, we want to limit the time the apparatuses are processing samples for the laboratory class.

Because considering 'money constraints' is an aspect of making 'informed decisions' (Table 1, item 6), costs per sample have been defined for each apparatus. These costs are based on the real costs, but sometimes also on the availability:

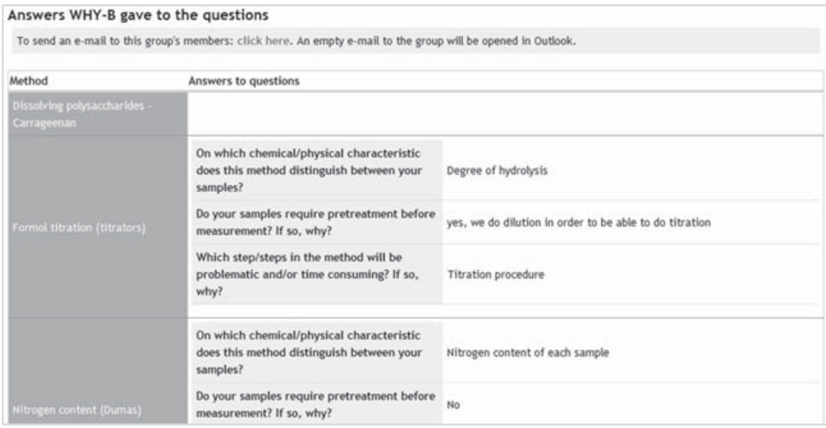
Apparatuses with little availability is made more expensive. The total cost of the research strategy is displayed in ExperD (Figure 2).

The deadline for finishing the research strategy is at the end of week 3, after which access to ExperD is blocked for the weekend. The initial research strategies are assessed by supervisors during the weekend.

In week 4 the actual laboratory class starts. On the first day of that week, student groups receive feedback on their research strategies from their supervisors. Student groups can access ExperD during the laboratory class via computers embedded in the laboratory benches. They can use ExperD to divide tasks among group members, keep track of their progress, update their research strategy and book apparatuses if necessary. The learning scenario ends on the last day of the laboratory class (Monday of week 6). Groups present their results to peer students during a symposium at the end of week 6.

Supervisor activities

During the first two weeks of the learning scenario, supervisors are available for feedback. They gently guide student groups to a good research strategy by asking questions and offering small hints if groups are stalling. Supervisors always have direct access on their computer to the up-to-date workflows their groups are designing in the ExperD. They also have access to a webpage on which all answers to the informed decision questions are listed (Figure 3).


Answers WHY-B gave to the questions

To send an e-mail to this group's members: click here. An empty e-mail to the group will be opened in Outlook.

Method	Answers to questions	
Dissolving polysaccharides - Carrageenan		
Formol titration (titrators)	On which chemical/physical characteristic does this method distinguish between your samples?	Degree of hydrolysis
	Do your samples require pretreatment before measurement? If so, why?	yes, we do dilution in order to be able to do titration
	Which step/steps in the method will be problematic and/or time consuming? If so, why?	Titration procedure
Nitrogen content (Dumas)	On which chemical/physical characteristic does this method distinguish between your samples?	Nitrogen content of each sample
	Do your samples require pretreatment before measurement? If so, why?	No

Figure 3. Supervisors have at any moment access to an overview generated by ExperD. This overview showed answers student groups gave to the informed decision questions.

As state before, supervisors give feedback on the initial research strategies at the beginning of the laboratory class (week 4). During lab work, supervisors can monitor student groups and bookings of apparatuses via ExperD or via the 'ExperD Booking Info' webpage on their pc or smartphone (Figure 4). This webpage enables supervisors to view bookings from three perspectives: All groups that planned a certain experiment, all experiments planned by a certain group and all experiments planned by all groups on a certain day.

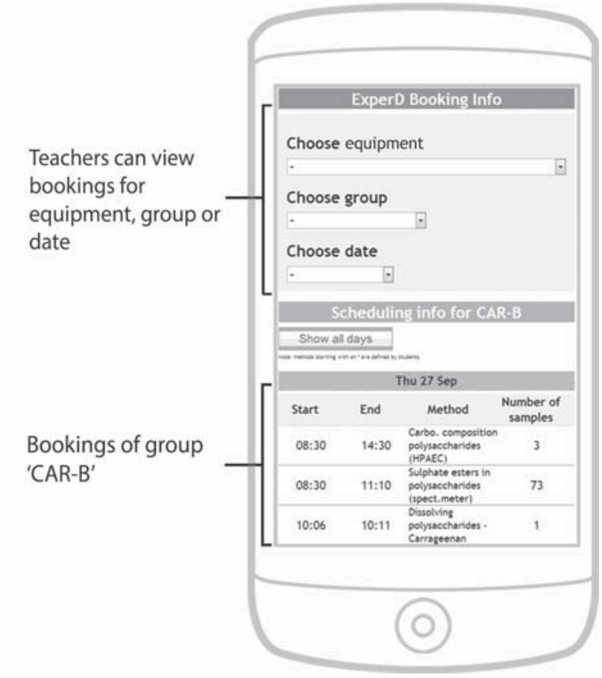


Figure 4. Supervisors can view booking info on their smartphones. In this example, the supervisor selected group 'CAR-B', and sees the apparatuses this group booked for today ('Thursday 27 September' in the figure). On the pc version of the webpage more information is available: When groups made the booking and the number of apparatus in use.

Case study

The learning scenario was implemented as planned during the 2012/2013 edition of the M.Sc. course 'Food Ingredient Functionality' in the fall of 2012, for which 142 students enrolled. The group size (of ~7 students) was unaltered because the laboratory class moved to a building on a different campus than the campus of the Laboratory of Food Chemistry and the Food Physics Group. Furthermore, it was the first year that the laboratory class was co-organized with the 'Education facilities' unit of Wageningen University due to a policy change. This unit is responsible for the practical aspects of the laboratory class: Glassware, small equipment, basic chemicals, etc. Because it was unclear how these changes would affect the organizational aspects of the laboratory class, the coordinator of the course did not want to also lower the group size for this year's edition of the laboratory class.

Students were allocated to 22 groups and these groups were supervised by 11 supervisors (7 Ph.D. candidates without educational training and 1 technical assistant as direct supervisors for particular student groups, 2 assistant professors as general supervisors for all groups and 1 technical assistant supervising particular apparatuses). One of the assistant professors is coordinator of the course. During the case study 2 moderately severe bugs in ExperD's booking system became apparent, which could not be solved in the time frame of the learning scenario. The first bug was discovered early during the laboratory class and concerned the dragging and dropping of bookings. Although there was an easy workaround for this bug, it confused quite some students. The second bug concerned the booking algorithm, which in rare cases gave 'false negatives' by rejecting correct bookings. This bug became apparent at the very end of the laboratory class and did not affect many groups. The 'ExperD Booking Info' webpage became available in the midst of week 3.

The learning scenario was evaluated by a student survey (held at the last day of the case study) and an evaluative supervisor group discussion (organized two weeks after the case study). The course coordinator categorized group's answers to the informed decision questions into three categories: 'correct answers', 'partly correct answers' and 'wrong answers'. Booking statistics were extracted from ExperD's database and - for apparatuses most likely to become overbooked - compared with the actual usage.

Collected data

The results of the student survey are listed in Table 3 (page 95). These results indicate that students found designing their research strategy a good preparation for the laboratory class. They found the workflow designed in ExperD a suitable format to communicate their strategy for this first part of the assignment, but less suitable for the second and third parts of the assignment. To a lesser extent, students indicate that designing a research strategy helped them to understand the theoretical background of the experiments. Many students had trouble using the booking system. Quite some groups indicate that they used apparatuses without booking for it, but once booked, apparatuses were available most of the times.

The learning scenario was discussed in a semi-structured way with a focus group consisting of the 10 supervisors of the course not involved in writing this manuscript (further referred to as the 'focus group participants'). The focus group participants were asked in a group discussion to comment on the following statements: "Next year, we should also let students design their research strategy in ExperD before the laboratory class starts", "My student groups made informed decisions on experiments", "We managed the booking and usage of apparatuses well this year" and "The ExperD booking web page is a helpful tool to supervise student groups" and where asked to comment on those statements. The most important outcomes of this group discussion are:

t1. For the first assignment ('identify unknown food ingredients'), all the focus group participants were satisfied with the way ExperD supported the preparation of the laboratory class and the communication between them and the groups. They agreed to have next year's student groups also design their research strategy in ExperD beforehand.

t2. The majority of the focus group participants noted that students struggled in upfront designing research strategies for the second ('influence of conditions on ingredients') and the third part ('design model system') of the assignment. The reason behind this is that these research strategies require iterations: perform an experiment, adapt research strategy, perform an experiment, etc. Registration of such iterations is well supported by ExperD. The majority of focus group participants did not realize that ExperD could also be used in the communication during these iterations. Consequently, many groups did not update their initial research

Table 3: Student survey results (n=140).

#	Question	Options* (%) 1	2	3	4	5	% 4+5
q1.	Designing a research strategy offered a good preparation for the laboratory class	0	3	13	52	32	84
q2.	Designing a research strategy helped me to understand the theoretical background of the experiments	1	6	17	48	28	76
q3.	A workflow was a suitable format to communicate our research strategy to our supervisors for part: • 'correctly identify unknown ingredient samples'	0	5	15	57	23	80
q4.	• 'describe and explain the properties of selected ingredients under various conditions'	1	16	23	50	9	59
q5.	• 'try to realize GrupVinck's envisioned application and explain why your selected ingredient works best.'	4	21	28	39	9	48
q6.	The maximum allowed samples (per day/for the laboratory class) triggered our group to think about what samples we really needed to measure in order to complete the GrupVinck assignment	1	15	24	39	21	60
q7.	The booking system was easy to use*	8	41	19	26	6	32
#	Question	A	B	C	D	E	%D+E
q8.	When deciding on a laboratory method our group considered: • multiple alternative laboratory methods.	0	9	27	50	13	63
q9.	• the costs of the laboratory method.	0	4	25	39	31	70
q10.	• the precision of those measurements.	0	9	27	45	18	63
q11.	• the time needed for that laboratory method.	2	7	15	39	36	75
q12.	• whether the sample had suitable physicochemical/chemical properties to be used in the laboratory method.	0	2	9	58	31	89
q13.	Our group used apparatuses without booking them.	24	28	36	12	0	12
q14.	Our group booked apparatuses, without using them.	42	39	17	2	0	2
q15.	When our group booked for apparatuses, it was available on that date and time.	1	1	21	40	37	77

*) 1=Totally disagree, 2=disagree, 3=agree nor disagree, 4=agree, 5=totally agree; A = never, B = seldom, C = sometimes, D = often, E = always.

strategy during the laboratory class, and used ExperD for booking purposes only.

t3. All the focus group participants agree that the answers to the informed decision questions helped them in identifying the theoretical shortcomings before student groups started working in the laboratory. They see this as an advantage of the learning scenario, because they could – in an early stage – identify groups with many theoretical shortcomings and give these groups extra support.

t4. None of the focus group participants recalled a situation in which apparatuses where overbooked. All the focus group participants remembered several occasions in which groups used apparatuses without booking for it, or groups bringing more samples to the apparatuses than they booked for. As long as there were no other groups who booked the apparatuses, these groups were allowed to continue using the apparatuses.

t5. All the focus group participants agree that the 'costs per sample' triggered students to think about whether they had to perform an experiment with a certain sample. A minority of the focus group participants were of the opinion that the 'costs per sample' was a too strong stimulus for students. So, groups would only perform the minimal number of experiments needed to complete the assignments, or sometimes even less. According to these participants, this is disadvantage of including 'costs per sample', because students will not get hands-on experience with all apparatuses.

t6. A minority of the focus group participants had a smartphone and could connect to the 'ExperD Booking Info' webpage using Wi-Fi in their laboratory classroom. These supervisors used the 'ExperD Booking Info' webpage (Figure 4) in their supervision with student groups and think it is a valuable addition to the laboratory class. They mainly used this webpage to get a quick idea of what the groups planned to on a certain day, or to check whether apparatuses were booked or not.

The course coordinator assessed a sample of the answers student groups gave on the informed decision questions. The aim of this assessment was to obtain additional support for t3 (see above), and to get an indication of the amount of time supervisors need for the assessment. The assessment took the co-author ~12 minutes per group. The results of the assessment are listed in Table 4. These results already suggest a large diversity between groups, both in the number of questions answered and the quality of the answers.

Table 4. Number of correct, partly correct and wrong 'informed decision questions' counted for 50% of the groups. One group (PEC A) did not answer any question.

Group	Correct answers	Partly correct answers	Wrong answers	Number of experiments
ALG A	2	2	3	7
ALG B	8	8	0	16
CAR A	16	2	2	20
CAS A	21	1	3	25
CAS C	14	2	1	17
GEL A	23	4	4	31
PEC A	0	0	0	20
WHY A	4	1	8	13
WHY C	15	3	4	22
XAN A	10	11	5	26
XAN B	20	4	4	28

From the midst of week 2 until the end of week 4 student groups could book apparatuses. The statistics of the booking system are listed in Table 5. On average, a student group makes 37 initial bookings. The group then rebooks each booking 2 times, after which it decides to cancel the booking in 74% of the cases. Finally, each group has booked 10 apparatuses for the laboratory class.

Table 5. ExperD booking statistics. Bookings were made by 22 student groups in ~2.5 weeks.

Number of initial bookings groups made	820
Number of times groups changed a booking date/time	1731
Number of bookings groups canceled	607
Number of final bookings groups made	213

As it were mainly the food physicochemical apparatuses which led to overbooking problems in the past, we decided to use these for the comparison between the booking timeslots and the actual use of the apparatuses. The times at which student groups started using the apparatus were noted for 6 physicochemical apparatuses on the Monday, Wednesday and Friday of week 4. This is the week where most groups were using physicochemical apparatuses. The resulting 52 starting times were compared with the booking times in ExperD (Figure 5). This figure shows that in 50% of the cases students used the apparatuses as booked. This is mainly caused by students who used apparatuses without booking them.

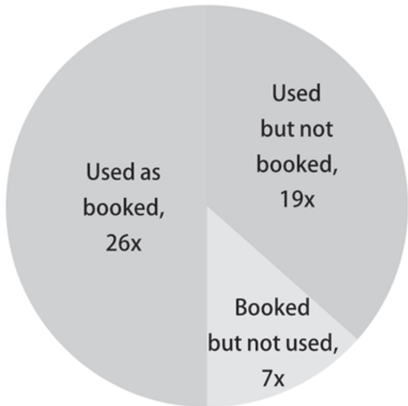


Figure 5. Comparison between actual usage and bookings of 6 physicochemical apparatuses on Monday, Wednesday and Friday of week 4. In total, these apparatuses where used 52 times.

Lessons learned

In the introduction of this paper we described two challenges. In this section we discuss whether we met these challenges.

We partly managed to warrant the quality of the research student groups designed, adjusted and conducted during the laboratory class. We are satisfied with the fact that students felt prepared for the laboratory class and that the focus group participants agree to this (q1, t1). Students could be triggered to think about the theoretical background of experiments while they design their research strategy (q2). The first part of the assignment required student groups to identify about 5 different food ingredients. Both students and the focus group participants agree that ExperD offers a suitable format for this part (q3, t1). Prompting student groups to answer informed decision questions helped supervisors identify theoretically less savvy groups (t3). The working definition of ‘informed decisions’ can be helpful to further improve the articulation of those questions. We are satisfied with the supervisors’ appreciation for the informed decision questions, as it gave them the opportunity to tailor their support to individual student groups (t3). We think that the results in Table 4 support this observation made by supervisors, as these results indicate e.g. that group ‘WHY A’ did not make informed decisions, whereas group ‘CAS A’ seemed to make them. Supervisors used this information in their feedback on the initial designs.

The open nature of the second and third part of the assignment made it difficult for groups to fully design the research strategies upfront (t2, q4, q5). The majority of the supervisors were insufficiently aware of the fact that the ExperD could also be used as a communication tool during these iterations (t2). This might be resolved by better instruction of the supervisors.

Furthermore, we have become aware of a constructive misalignment between the intended outcomes of the laboratory class (student groups keeping their research strategy up to date) and the assessment. This gave student groups an escape route of not keeping their research strategies up to date. In our view, planning and keeping an up-to-date lab journal are established best practices in the laboratory. Therefore, it is reasonable and realistic to add ‘keep planning up-to-date’ and ‘keep lab journal up-to-date’ to the learning outcomes of the course.

We managed to give students the freedom to book apparatuses without supervisors losing control and without risking overbooking of apparatuses. We are satisfied with the fact that we could offer students the freedom to book their apparatuses, and that students and supervisors did not recall major problems with the availability of apparatuses (q15, t4). However, we have strong indications that groups often perform experiments without booking apparatuses, or forget to unbook apparatuses they no longer need (Figure 5, q13, t4). Based on these findings it might be argued that it is unnecessary to let students book apparatuses in ExperD’s booking system. We disagree, because of the following reasons. Firstly, ‘being able to book experiments’ is an important aspect of the course’s learning objective ‘being able to design and conduct research strategies’. Secondly, we think that requiring students to book apparatuses gives students and supervisors a decisive argument in the case of conflicts: The group that booked can use the apparatuses. Thirdly, the numbers in Table 5 show that there is a need for a flexible booking system, which is very difficult to accomplish with e.g. paper sign up lists. Our hypothesis is that the learning scenario succeeded in making students think about what samples they had to measure and what samples could be omitted. The costs per sample might have contributed to this awareness (t5, q9) and – to a lesser extent – the limits on the number of samples students could enter (q6). This led to a significantly lower number of samples than we had estimated based on our experience of previous years. Because of this, there was an overcapacity of apparatuses. This might have decreased the incentive to book apparatuses: Many groups found out that they could use apparatuses without creating conflicts with other groups. So the 'safety net' offered by ExperD was not needed because we managed – using ExperD – to limit the number of samples to be measured. Alternatively, the incentive to book apparatuses might also have decreased because students found ExperD's booking system rather difficult to use (q7). We think this can be improved by spending more time on explaining ExperD to the students, but also by resolving the two bugs which were present during the learning scenario.

Some of the focus group participants mentioned that, because of the costs, groups would only perform the minimal number of experiments needed to complete the assignments. As long it is not 'less than needed', we are satisfied with this result. On the other hand, our aim was not to turn students into 'penny-pinchers', whose main focus is to obtain a cheap research strategy. We think we can overcome this by giving students a budget (e.g. €5000,-). Students will then be encouraged to design a research strategy, whose costs are within the 10% range (plus or minus) of this budget. This new set-up can still limit the number of bookings, whilst preventing groups from focusing too much on minimizing the costs.

Students worked in groups of 7, which might be unfavourable because of the so-called 'free-riders' problem and because the relatively low number of experiments individual students have to carry out in the current set-up. Because of external circumstances (see 'Case study'), the organizers of the course did not dare to lower the group size for this year's edition of the laboratory class. Based on the experiences with the learning scenario, it has been decided to lower the group size to 5 for the 2013/2014 edition, and possibly to 4 for the 2014/2015 edition.

There is a design opportunity: A (mobile) 'group progress' webpage for supervisors. The research presented in this manuscript suggests that there is a design opportunity: A (mobile) webpage for supervisors at which they can follow student group's progress during the laboratory class. When student groups are allowed to plan their own experiments, it can be difficult for supervisors to monitor their progress. A (mobile) 'group progress' webpage might be a tool to facilitate this monitoring. The 'group progress' webpage would contain the same information as the current 'ExperD Booking Info' website (Figure 4), together with e.g. information on the changes students made to their strategy, answers to informed decision questions and experimental results. Supervisors might then have a quick look on the webpage to prepare for their discussions with students. Besides, the mobile webpage might help to quickly resolve conflicts in cases groups did not book for apparatuses. A prerequisite for this webpage to function is that students keep their workflow updated. Once the supervisors can at any time view the status of the workflow of each group on their smartphone, the supervisors will be more aware of the workflows that need to be updated.

Conclusions

We conclude that we partly managed to warrant the quality of the research students designed, adjusted and conducted during the laboratory class. We managed to give students the freedom to book apparatuses without supervisors losing control and without risking overbooking of apparatuses. Based on the experiences with the learning scenario, it has been decided to lower the student group size for next year's edition of the laboratory class from 7 to 5. Finally, we think there is a design opportunity: A (mobile) 'group progress' webpage, which gives supervisors instant information on apparatuses bookings, groups' answers to 'informed decision questions' and experimental results.

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6. General discussion

Introduction

In the forgoing chapters we described various components of a laboratory electronic performance support system (labEPSS) for food chemistry laboratory classes. The components of labEPSS were instantiated during a research project, in which a design-oriented research approach was taken. The aim of labEPSS was to meet the following design goals:

- to avoid unnecessary cognitive load induced by the instructional format of the laboratory class (further referred to as the *cognitive load* design goal: 'CL');
- to let students prepare for their laboratory class (*prepare* design goal: 'PP');
- to support the communication between students and between students and supervisors (*communication* design goal: 'CO');
- to give students the freedom to plan their experiments without supervisors losing control and without risking overbooking of apparatuses (*freedom* and *control* design goal: 'FC');

The aim of this chapter is to propose the overall design of labEPSS and to discuss how labEPSS can be helpful in reaching the above goals. The overall design is described in terms of required functionalities of labEPSS. The rationale for these functionalities is based on the evaluations described in the forgoing chapters and/or on theoretical considerations.

The following vocabulary is used. We distinguish between three user roles: 'student', 'supervisor' and 'teacher'. In the laboratory class, 'students' receive support from 'supervisors'. At the Laboratory of Food Chemistry (LoFC) most of the supervisors are Ph.D. students without formal educational training. One or two supervisors belong to the technical staff of LoFC, who also do not had formal educational training. Finally, the 'teacher' is responsible for the contents of the laboratory class. At LoFC teachers are usually assistant professors. Students can be assigned to 'student groups' in labEPSS. Student groups serve as a 'tag', used by labEPSS to combine information that the individual students add. Students perform 'experiments' during the laboratory class, for example 'Determination of protein content according to Bradford'. The way an experiment should be carried out is described in a 'laboratory method'. The description of a laboratory method usually contains a 'laboratory method introduction' , in which the theory behind the experiment is explained, and one or more 'laboratory method steps'.

Laboratory method steps describe the actions students have to take to perform the experiment, e.g. 'Add 2 ml reagent to each tube'.

The labEPSS components

LabEPSS consist of two major components: ExperD and LabBuddy. ExperD and LabBuddy are 'web applications', meaning that they can be used on any device with a HTML5/CSS3/JavaScript capable browser. This comes with constraints regarding the laboratory in which the laboratory class is given: For labEPSS to function this laboratory should have sufficient computers with internet access at the lab benches (at least one per student / student group) and/or sufficient WiFi hotspots to support wireless devices.

The main functionalities of ExperD are to support students in designing a research strategy, to structure laboratory work and to assist in the booking of apparatuses. The first main functionality of LabBuddy is let students prepare for individual laboratory experiments. The second main functionality is to provide all information students need to meaningfully, correctly, efficiently and safely carry out laboratory experiments. The third main functionality is to store information students collect (e.g. results) while carrying out experiments.

Figure 1. Overview of labEPSS components ExperD and LabBuddy

ExperD

Designing of workflow of operations

In chapter 3 we established that there is a need in the 'Food Chemistry' model laboratory class for a tool enabling students to design a workflow of experiments. This tool could help students to see the relations between experiments ("have the overview") and support the communication between student groups and the supervisors. Students can design workflows in ExperD. Such a workflow consists of connected 'operations'. An 'operation' can either be an experiment, a set of experiments or a part of an experiment. The rationale for this abstraction is that it makes ExperD usable in laboratory classes in which students e.g. have to design an experiment in detail. Operations can be either supervisor defined or student defined. Supervisor defined operations are shown in a list, from which students can choose. Student defined operations can be added to that list while students work in ExperD. Each operation can have one or more input ports ('in') and output ports ('out'), by which it can be connected to other operations. Students establish connections between operations by dragging an 'out' port of one operation and dropping it onto an 'in' port of another operation (or vice versa). Via these connections samples and/or information go from one operation to the next. An example is given in Figure 2-3.

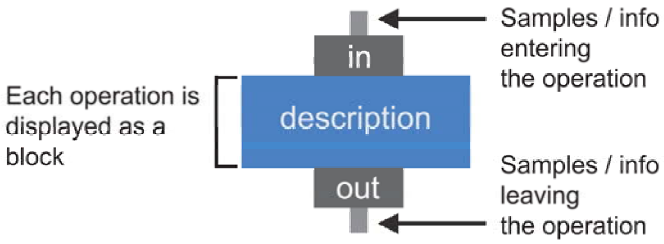

Figure 2. Example of an operation in ExperD. An operation in ExperD is displayed as a block with ingoing and outgoing ports.

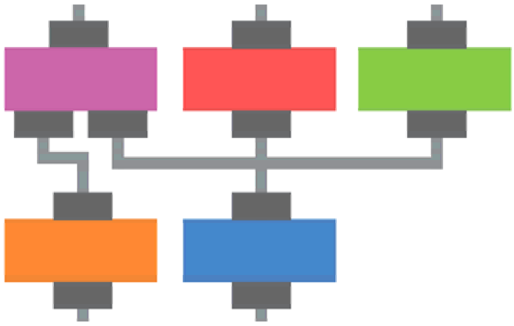

Figure 3. Students design a workflow of operations in ExperD.

Using a web form, students can add 'operation information' to operations, e.g. experiment results, Excel sheets and pictures. Finally, students can add text boxes to the workflow, e.g. to annotate the research strategy. Students can keep track of their progress in executing the workflow by changing the status of operations. By default this status is 'not started', which can be changed into 'in progress' or 'finished'. The status of an operation is visible in ExperD's user interface. The student group work is supported by ExperD as it offers the possibility to create groups, of which the individual students have access to the same workflow. The students in a group can divide tasks by assigning operations to individual students within the group. Which operation is assigned to which student is visible in ExperD's user interface.

All of above functionalities have been realized and evaluated. In chapter 3 it was concluded that students of the 'Food Chemistry' course can be supported by the workflow functionality of ExperD. In this laboratory class students designed a workflow beforehand, which they used and adapted during their laboratory experiments. Students found it useful to design the workflow and it helped them to figure out what to expect during the laboratory class. We also have indications that working with the workflow in the laboratory helped students to keep the overview. We think that these findings suggest that ExperD helps to avoid extraneous cognitive load in the laboratory class (design goal: CL), as it gives students the overview of all operations they have to carry out. Furthermore, ExperD can be of help in the communication between students and supervisors during the laboratory class, because it formalizes the communication about the research strategy (CO). This is in line with our findings in chapter 5 for students of the M.Sc. course 'Food Ingredient Functionality'. In this chapter, we found out that students felt prepared for the laboratory class after designing their research strategy in ExperD (PP). As to communication, we only found evidence that the workflow supports the communication when the design does not involve iterations that are based on measurement results. We did not find evidence that the workflow supports the communication when the design involves iterations. This is also the case for the extent to which students felt prepared for the laboratory class. However, these findings could also be explained by a constructive misalignment between the intended outcomes and the assessment of that particular 'Food Ingredient Functionality' laboratory class.

Booking tool

In chapter 5 it was established that there is a need for a flexible apparatus booking tool in the 'Food Ingredient Functionality' laboratory class, which prevents overbooking of apparatuses by putting constraints on the amounts of samples students can process.

In ExperD, operations can be linked to one or more apparatuses, which can be booked by students. Apparatuses can also be linked to multiple operations. For each apparatus the following 'planning parameters' can be set: The number of apparatuses available, the date/time slots the apparatus is available (optional), the batch size (e.g. '4 centrifuge tubes per centrifuge run', optional), time needed per sample/batch, costs per processed sample (optional), constraints on the number of samples students/groups are allowed to process (e.g. '6 samples per 24h', optional). Booking is done automatically. Students should enter the number of samples they want to process (or the amount of time they need the apparatus) and the desired starting time. Using these parameters the system checks the availability. If the apparatus is not available on the desired starting time, the system proposes the next available starting time. In the booking system students can view their own bookings and the bookings of other students/student groups.

Except for the many-to-many relationship between apparatuses, all of above functionalities have been realized. The booking system was evaluated in the 'Food Ingredient Functionality' laboratory class (chapter 5). Although we found that there can be situations in which students do not book all their apparatuses, the booking system offers a decisive argument in case of conflicts between students. We also have indications that the planning parameters help to prevent overbooking of apparatuses, because they stimulate students to think about what experiments they really want to perform (FC). Because the booking system is visually integrated in ExperD, unnecessary cognitive load because of booking is avoided (CL).

Hooking into design process

In chapter 3 and especially in chapter 5, it was established that students could be supported in the laboratory class by asking them questions during the design process.

ExperD offers possibilities to 'hook into' the design process by asking open or closed 'design questions' while students are designing a workflow. These questions can appear when students add, select, update and delete operations. Both the open and closed questions can be used to trigger students to think e.g. about the operation itself or why it is added it to the workflow. Additionally, students can receive feedback on the order of operations. Finally, the system can ask students to define properties of samples and/or information leaving the operation (Figure 4).

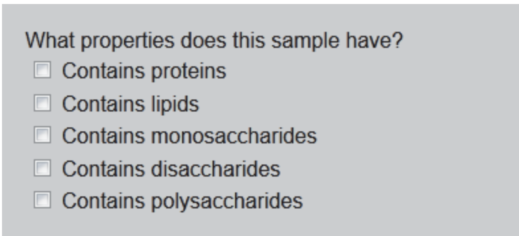

Figure 4. Web form asking students to define the properties of a sample.

Students receive feedback on how they defined these properties, either directly, or when they connect the operation to another operation.

Two of above functionalities have been realized and used in the model laboratory classes: Asking open or closed 'design questions' and asking students to define sample properties / giving feedback on those properties. Of these functionalities, only the first one has been evaluated by students and supervisors during the course 'Food Ingredient Functionality' (chapter 5). In that case study we found that students can indeed be triggered by open questions to think about the theoretical background of experiments while they design their research strategy. The answers to these questions – which were not correct in some cases – can also help supervisors to identify theoretical shortcomings before students start working in the laboratory. Based on these shortcomings, supervisors can tailor the feedback they give. We think that asking to define sample (or: information) properties and giving feedback on those properties can improve the students' understanding of the theory behind operations (PP).

Realizing the possibility of asking the other design questions would give teachers even more tools to scaffold students' thinking during the design process. The answers to all these questions would form a 'design rationale', which could be of help for students and supervisors while discussing the research strategy (CO).

Specific functionalities for supervisors and teachers

Teachers have the possibility to configure ExperD to bring it in line with the learning objectives of the laboratory class. Each functionality of ExperD can be made available or unavailable during the laboratory class. Teachers also decide which operations are shown in the list of operations students can add to the workflow and whether students can add their own operations. In addition, teachers can add the 'design questions' to ExperD and configure the feedback students receive on the closed questions, the order of operations or the sample properties. Supervisors of the laboratory class have access to all student workflows and bookings, and can make changes to these workflows and bookings (FC).

LabBuddy

Enriched laboratory method texts

In chapter 2 it was established that the (printed) laboratory manual contains much implicit information, e.g. what chemicals and apparatuses look like, where they can be found, how to perform a laboratory method step, etc. This format might cause extraneous cognitive load, because students have to mentally combine different sources of information. A web based laboratory manual could prevent this kind of overload, by presenting procedural information just-in-time

(Merrienboer & Kirschner 2007), while obeying the contiguity principle (Clark & Mayer 2007).

LabBuddy contains 'enriched' laboratory methods. With this we mean that LabBuddy not only contains the full 'plain' laboratory method text (usually a theoretical introduction and a list of laboratory method steps), but also additional supportive/procedural information and helper utilities. All the information in the laboratory method can be categorised as information answering five short questions: 'what?', 'why?', 'when?', 'where?' and 'how?'.

The 'what?' information (the laboratory method steps) is presented in two forms: The concise and expanded form (Figure 5).

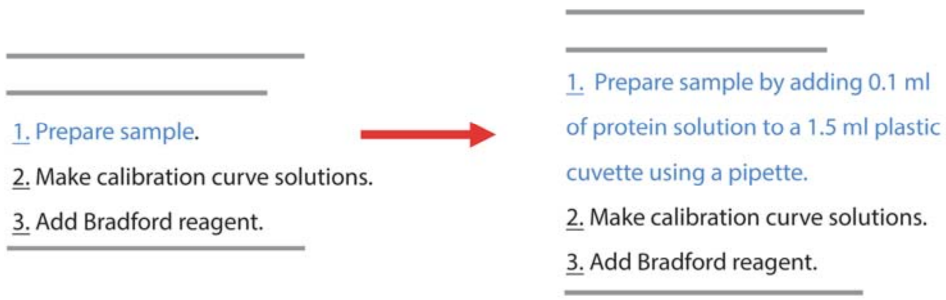

Figure 5. The laboratory method step texts ('what?' information) are initially presented in a concise form. After a student action, e.g. pressing a button, the expanded form is shown.

Initially, the concise form is presented to students, in which the main aim of the laboratory method step is presented. Students can use this information while preparing the experiment, as it gives them a quick overview of the method steps. After e.g. clicking on a button, the expanded form is shown to the student, which gives details like: What apparatuses and chemicals are needed, what actions should be taken, etc. In the expanded form, students can see how chemicals and apparatuses look like by e.g. clicking on the name of the chemical or apparatus name (Figure 6). Students can use this information just before carrying out the laboratory method step.

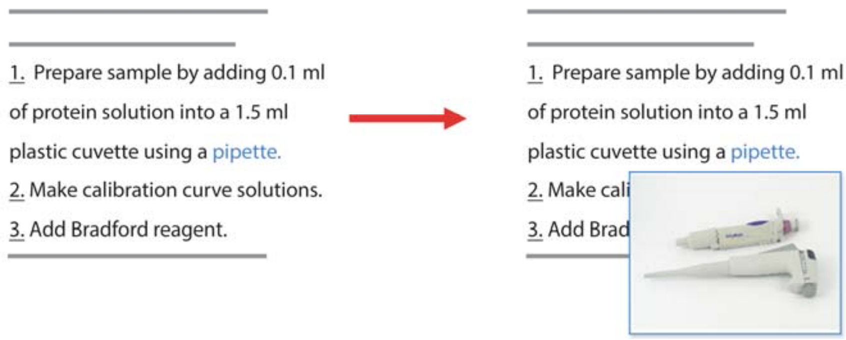

Figure 6. Pictures of chemicals and apparatuses can be made visible e.g. by clicking on the name of the chemical or apparatus

The 'why' supportive information consists of the theoretical background of the laboratory method steps. Students can use this information to prepare themselves for the experiment, as it give them clues about what should be observed. The 'when?' procedural information consists of an estimation of the time needed for each step as well as information on whether the experiment can be paused after each step. As most laboratory classes are time boxed (e.g. from 8:30h – 12:30h) this information can help students in estimating whether they have enough time to perform an experiment (or a part of the experiment). The 'where?' procedural information consists of the locations of chemicals / apparatus required for the laboratory method, as well as information on where used chemicals can be discarded. Students can use this 'where' procedural information just before starting the experiment or when cleaning their lab benches after the experiments has been finished. Finally, the 'how?' procedural information consists of practical advices on how to efficiently and safely perform the laboratory method steps. For example: 'The pH can change very fast, so add the NaOH drop by drop.' Such information can either be presented as text or as instruction videos and students can use this information while they are carrying out the experiment.

Besides the information-related elements, small helper utilities in the laboratory method support students while carrying out their experiments. Integrated count-down timers (Figure 7) help students to carry out multiple experiments at the same time. Tailored calculators can help students to calculate concentrations, dilutions, amounts, etc. Finally, chemicals/small equipment and bookable apparatuses can be presented in a 'shopping list' format, giving students an overview of the resources they need in the laboratory method.

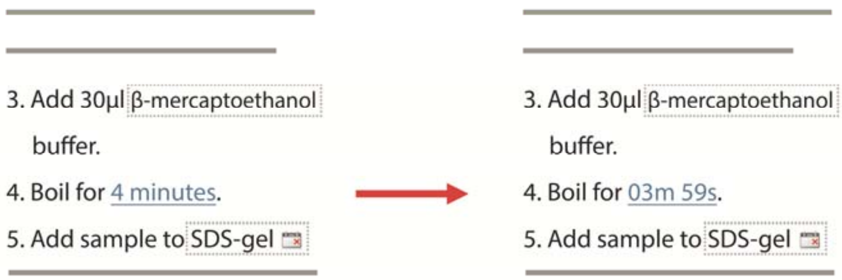

Figure 7. Example of a timer 'helper utility' integrated in the laboratory method text.

Almost all these functionalities have been realized and evaluated by students of the 'Food Chemistry' laboratory class (chapter 2). The results suggest that a large majority of students preferred to use webLM on their laboratory bench instead of their printed laboratory manual. We hypothesize that this is the case because the webLM is indeed avoiding cognitive load (CL). The 'smartphone version' of webLM (a prototype of LabBuddy) was used by 7 out of 26 students who owned a smartphone (chapter 4). We think that the percentage of students who use LabBuddy on their smartphone will increase in the near future, as smartphones will be more and more integrated into student's lives. Based on this consideration, we concluded that the LabBuddy should work on all HTML5 capable devices, independent of screen size (chapter 4, 'Design requirements LabBuddy').

The unrealized functionalities concern the 'tailored calculators' and the shopping lists. Realizing these tools could avoid extraneous cognitive load caused by these respective calculations and shopping activities (CL).

Activating exercises in laboratory method texts

Although LabBuddy offers students much information, it is not activating students to make use of that information. This is confirmed by the supervisors of the course 'Food Chemistry' (see chapter 2). Diederen (2003) asserts that digital exercises can activate students, and thereby stimulate them to learn.

The 'what', 'why?', 'when?', 'where' and 'how?' information can also be presented in LabBuddy as (closed) 'preparative questions' with feedback. In this way, the laboratory method turns into an activating exercise. The system can ask students to complete this exercise to prepare themselves for the laboratory class. The first time they open the laboratory method, it looks like an exercise with a couple of questions (Figure 8). Once they answered all the questions, the 'normal' laboratory method is shown, as described above. We will now give examples for each question type.

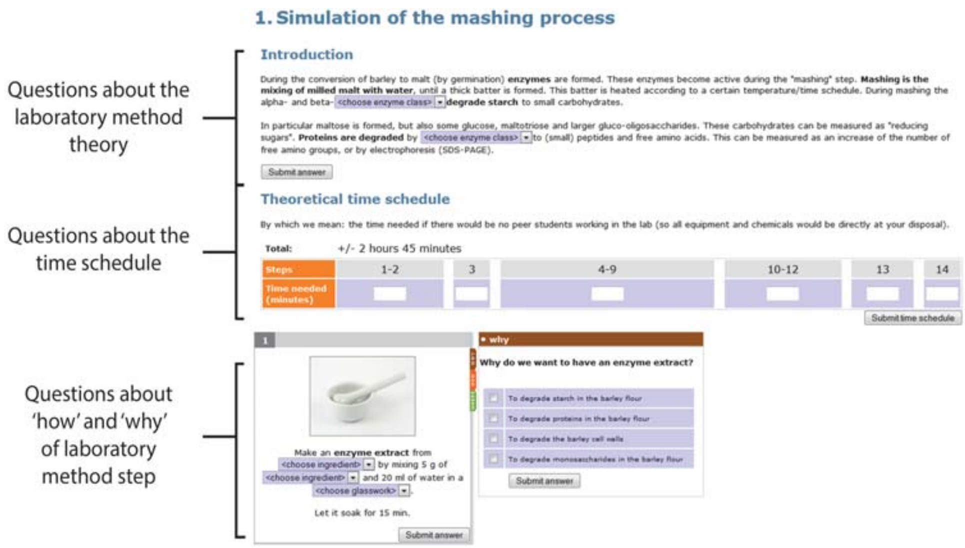

Figure 8. Examples of activating elements in a laboratory method text.

The 'what' preparative questions can trigger students to think about the subsequent operations in the laboratory method step. For example, the system can ask students to put a number of laboratory method steps in the correct order. In doing so, students are triggered to carefully consider what they will do when they carry out the laboratory method. The 'why' preparative questions can trigger students to think about the theoretical background of laboratory method as a whole, or of certain aspects of laboratory method steps. For example: 'The amount of which chemical compound is measured in determination of proteins according to Dumas?' and 'Why do you add McIlvain-buffer in this step?' These questions can also stimulate students to think about what is the 'noise' while carrying out the laboratory method step, and what is 'signal'. For example, a question about a colour reaction might prepare the student's mind for the change of colour he or she should expect in that particular laboratory method step. The 'when' preparative questions can trigger students to make good estimations of the duration of laboratory work. For example, the system can ask students to estimate how many minutes certain steps take, or they can be asked to order the steps from the longest to the shortest. Students can also be asked after which steps the method can, or cannot be paused. Additionally, they can be asked to come up with arguments why the method can/cannot be paused after those steps. The 'where' preparative questions can focus on the discarding of chemicals, e.g. 'Which of the following solutions can be discarded in the sink?' Next, students can also be asked why this is the case, e.g. 'Why should Nelson A1 reagent be discarded in the heavy metals waste barrel?'. Finally, the 'how' preparative questions can trigger students to think of alternatives.

Above functionalities could be used to further trigger students to prepare for individual laboratory experiments (PP).

Capturing and sharing knowledge assets

During the laboratory classes of LoFR students work in groups. In most cases, individual group members perform experiments and gain results from these experiments. Students also have to write down information when performing the experiments, e.g. the exact weight of a sample.

LabBuddy offers students the possibility to add information to laboratory method steps. This can either be written or typed notes, files and – in the case it is used on mobile devices - photos, videos and sound recordings. In case of group work these 'knowledge assets' can be shared amongst group members and with other groups. This capturing of knowledge assets can also take place in a more formalized form by means of open or closed 'knowledge capturing questions' with feedback defined by the teacher. These questions appear in the laboratory method text, after the student finished the preparative questions. Thus, students are triggered to make certain observations, which they might otherwise forget. For example: 'What colour does your sample have after you have added the reagent?' In the case of a closed question, the system can give feedback on the answer, pointing the students on problems with his or her sample. For example: 'Your sample is too dark for the spectrophotometer. Please make a dilution'. LabBuddy contains an overview page, which contains all knowledge assets captured in all laboratory methods and – if applicable – of all student group members.

These functionalities have been partly realized in the LabBuddy prototype: The adding of notes and attachments (chapter 4). Most students (5 out 7) who used the LabBuddy prototype found these useful functionalities (chapter 4). Realizing the possibility to directly upload photos, videos and sound recordings from the camera/microphone to a website is currently constrained by a lack of support in many mobile browsers*.

Exporting and printing laboratory methods

Because a minority of the students has a HTML5-capable smartphone and a minority of that minority used the LabBuddy an additional constraint is that a student should be able to print the lab methods.

Laboratory methods in LabBuddy can exported to common formats like Microsoft Word or PDF. Likewise, LabBuddy also can export knowledge assets, categorized by laboratory method or by student (in case of group work). Students can use these while writing their report. Each exported laboratory method contains a QR code leading back to the laboratory method in LabBuddy. This functionality has not been realized.

Specific functionalities for supervisors and teachers

Again, teachers have the possibility to configure LabBuddy to bring it in line with the learning objectives of the laboratory class. Each functionality of LabBuddy can be made available or unavailable during the laboratory class. For example: 'How' information is displayed in the B.Sc. 'Food Chemistry' laboratory class, but absent in the M.Sc. 'Food Ingredient Functionality' laboratory class. Teachers can also assign laboratory methods to individual students or student groups (in the case LabBuddy is used separately from ExperD).

At an overview page in LabBuddy, supervisors can see which laboratory methods are currently being viewed by students, and which they have opened in the past. This gives the supervisors clues about student activities and progress.

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* See e.g. http://caniuse.com/stream for a browser comparison chart. A possible solution to this problem would be to distribute LabBuddy not as a 'pure' web app, but as a so-called 'hybrid app', using e.g. Apache Cordova (http://incubator.apache.org/cordova). This boils down to supplying a mobile browser supporting these functionalities, which automatically loads the LabBuddy web app.

Supervisors can also see which students have finished which preparative questions. Furthermore, they have access to both the knowledge asset overview pages of all students. This can give supervisors clues about the quality of the work of individual students.

How the labEPSS components cooperate

Although the LabBuddy and the ExperD can be used as separate tools, they are designed to work together, offering an integrated experience. In this section we will discuss the various aspects of this integration.

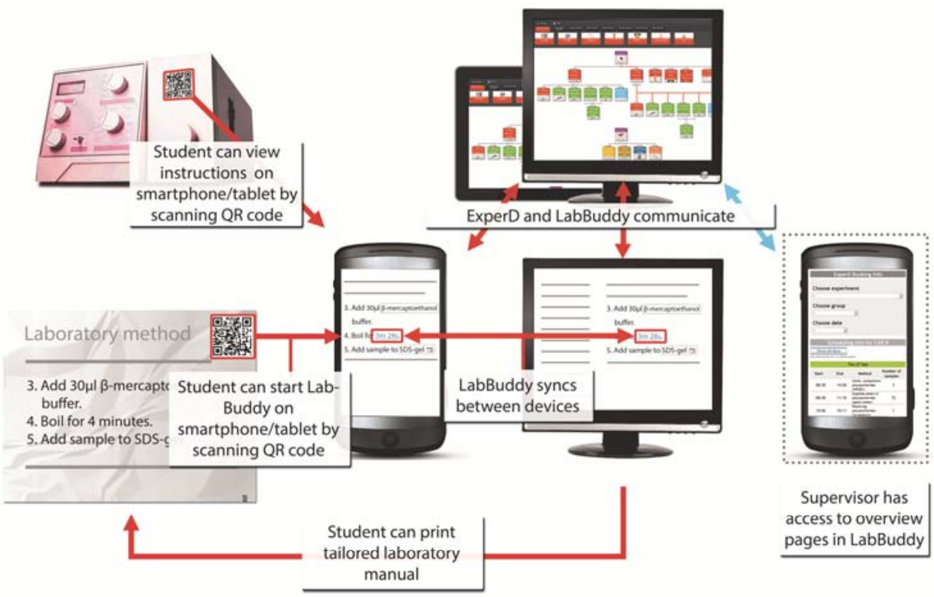

Figure 9. How labEPSS components cooperate.

Operations in ExperD can be linked to laboratory methods in LabBuddy. Operations having a linked laboratory method become visible in LabBuddy once they are added to the workflow in ExperD. In case of group work, operations assigned to individual students in ExperD are highlighted in LabBuddy of those students.

ExperD and LabBuddy communicate: changes in operations in ExperD are reflected in related laboratory methods in LabBuddy (and vice versa). The status of an operation in ExperD ('not started', 'in progress' or 'finished') is visible in LabBuddy, and can also be changed in LabBuddy. Countdown timers in LabBuddy are also shown in ExperD, giving students an overview of all running timers. If pending questions are present in LabBuddy, this is made visible in ExperD (Figure 10).

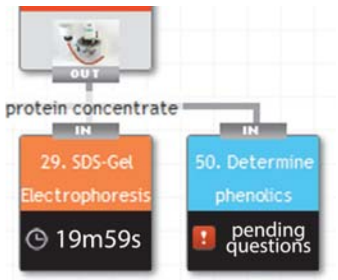

Figure 10. Countdown timers are shown in ExperD. Students are also notified when there are pending preparation or knowledge capturing questions in LabBuddy.

In LabBuddy, students can view booking information of bookable apparatuses present in the laboratory method text, and can either postpone or bring forward these bookings (Figure 11).

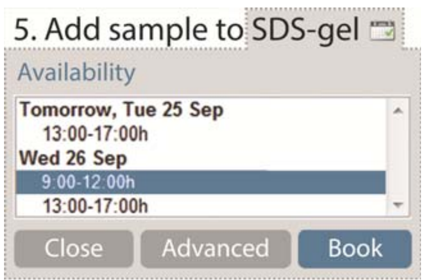

Figure 11. Students can perform simple booking operations in LabBuddy

Switching between the components, switching between media and switching between devices should offer an integrated experience to students. The laboratory method in LabBuddy can be opened from ExperD by clicking on a hyperlink in ExperD. Similarly, QR codes on apparatuses lead to instruction movies in

LabBuddy. Equipment can be used in several laboratory methods and the instruction movies are included in those laboratory methods. Based on e.g. the status of the related operation ('in progress') or the laboratory methods of operations assigned to the individual student, LabBuddy makes an educated guess. It then opens the most likely laboratory method (or presents students a shortlist of likely laboratory methods). Students can also easily synchronize the views of two devices, e.g. by clicking a button in a laboratory method loaded in LabBuddy on the computer, this laboratory method is immediately loaded on the student's smartphone.

Teachers have access to an overview webpage in LabBuddy, showing all operation information students entered in ExperD. On another webpage supervisors can view the answers students gave on the open and closed 'design questions' (questions asked during the design of the research strategy).

The 'cooperation' functionalities have no yet been realized. Once in place, they are likely to avoid cognitive load, as students do not have to remember by heart which experiments are relevant for their own laboratory class, do not have to browse through a laboratory manual, have the overview of running timers, etc. (CL).

Concluding remarks

The goal of labEPSS is to overcome the four design challenges described in the introduction. In Table 1 the functionalities of labEPSS are related to the goals. From this table it concluded that labEPSS, once fully realized, is capable of meeting the the goals. The labEPSS is likely to avoid extraneous cognitive load by presenting information just-in-time in a visually integrated manner. It offers several functionalities which can stimulate students to prepare their laboratory class experiments: Design of a research strategy, answering design questions while designing this strategy and activating exercises in the laboratory methods. LabEPSS can also aid in the communication, it enables students to present their research strategy in a formalized manner. It also allows student group members to keep each other updated and to share knowledge assets. Finally, labEPSS give supervisors several tools to manage laboratory classes. It allows for preventing the overbooking of apparatuses by putting constraints on the amount of samples students can process. Using several overview pages it also gives teacher's tools to scaffold student's thinking, by asking students to answer questions during the design of the research strategy, during the preparation for laboratory experiments and during the execution of the experiments.

Table 1. Mapping of labEPSS functionalities to design goals.

ExperD functionality	CL	PP	CO	FC
Designing of workflow of operations				
Booking of apparatuses				
Hooking into the design process				
Specific functionalities for supervisors and teachers				
Cooperation with LabBuddy				
LabBuddy functionality	CL	PP	CO	FC
Enriched laboratory method texts				
Activating exercises in laboratory method texts				
Capturing and sharing knowledge assets				
Specific functionalities for supervisors and teachers				
Cooperation with LabBuddy				

LabEPSS offers the possibility to slowly remove scaffolds during the curriculum. So a 1st year laboratory class, in which students are at the 'novice' end of the 'novice'-'expert' spectrum, all functionalities could be make available to students. In a 2nd year laboratory class, were students (hopefully) advanced somewhat to the 'expert' end of the spectrum, some elements can be made unavailable, e.g. the 'tailored calculators' in the LabBuddy, because students at that level should be able make these calculations without guidance. Finally, because of its flexibility, it is likely that labEPSS can also be used to support students, supervisors and teachers during laboratory classes not related to the field of food chemistry.

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Summary

The research described in this thesis deals with the design, realization, implementation, use, and evaluation of an electronic performance system for food chemistry laboratory education (labEPSS). This research was conducted at Laboratory of Food Chemistry (LoFC) at Wageningen University, Wageningen, The Netherlands.

Chapter 1 gives the general introduction to the thesis. In food chemistry laboratory classes, students work with complex food systems and sophisticated analytical equipment to purify, characterize and modify individual constituents to obtain certain bio- or techno-functionalities. Four design goals related to food chemistry laboratory classes were identified. Firstly, labEPSS should avoid extraneous cognitive load caused by the instructional format of the laboratory classes. Secondly, labEPSS should let students prepare for their laboratory experiments. Thirdly, labEPSS should support the communication between students and between students and supervisors. Fourthly, labEPSS should give students the freedom to plan their experiments, without supervisors losing control and without risking overbooking of equipment. To address these goals, several web-based tools where developed.

Chapter 2 describes the design, usage and evaluation of a web based laboratory manual (webLM). The main aim of the webLM is to support students while working in the laboratory by providing them with just-in-time procedural information. The webLM was introduced to the 2008 edition of the B.Sc. course 'Food Chemistry' at the Wageningen University. Desktop computers with an internet connection were installed on the lab benches, giving each group access to one pc. Besides the electronic version, students received a printed copy of the laboratory class manual. The evaluation showed a positive attitude towards the webLM by both students and supervisors. Most students strongly prefer the web-based lab manual over the printed version, and find the former one easy to use. Some supervisors argued that the webLM is not activating students to use the information offered. Making the webLM more interactive might be an interesting design challenge. Furthermore, it was established that the webLM can be a promising research tool to monitor student behaviour in the laboratory classes.

Chapter 3 describes the design, use, and evaluation of a web-based experiment designer, denoted ExperD. 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 the course 'Food Chemistry' at Wageningen University in The Netherlands. Both evaluations showed that students find ExperD helpful and that supervisors see the ExperD as a valuable addition to the laboratory class. Usage logs showed that students used the tool throughout the entire laboratory class and kept their research strategies up to date. Furthermore, the ExperD also proved to be a promising research tool for monitoring both student design activities as well as student actual lab work activities.

In chapter 4 the potential of smartphones and tablets to support students in the laboratory class is explored. Increasingly, mobile applications appear on the market that can support students in chemistry laboratory classes. In a multiple app supported laboratory, each of these applications covers one use-case, e.g. to make a dilution calculation. In practice, this leads to situations in which information is scattered over different screens and written materials. Such a multiple app supported laboratory will become awkward with the growth of the number of applications and use cases. In particular, using and switching between applications is likely to induce extraneous cognitive load that can easily be avoided. The chapter describes the design of a smartphone web app called 'LabBuddy'. LabBuddy provides an integrated presentation of information from various resources conform guidelines from literature on user interfaces. The chapter describes a small case study of the use of a LabBuddy prototype in such a laboratory class. Based on the evaluation of this case study, design requirements for LabBuddy were articulated. LabBuddy should work on HTML5 capable devices, independent of screen size, by having a responsive layout. In addition, LabBuddy should enable a student using LabBuddy to switch between devices without much effort. Finally, LabBuddy should offer an integrated representation of information.

In chapter 5 another case study is described, which took place in the M.Sc. course 'Food Ingredient Functionality'. Inquiry laboratory classes are suitable to acquire academic skills, such as designing research strategies and independently carrying out research. Due to their open nature, guided inquiry laboratory classes can be more difficult to manage than laboratory classes of a relatively closed nature, such as expository or verification-based laboratory classes. To cope with the organisational challenges of a guided inquiry M.Sc.-level food technology laboratory class a computer assisted learning scenario was developed. Central in this learning scenario is an extended version of ExperD, which handles the booking of equipment and enables monitoring of students' progress. From the evaluation it was concluded that the learning scenario was successful. Based on the evaluation, recommendations to improve the learning scenario are formulated, as well as suggestions for a mobile webpage that enables supervisors to keep track of student group progress in the laboratory.

In chapter 6 an overall design of labEPSS is proposed that consists of LabBuddy and ExperD. LabBuddy is based on the webLM (chapter 2) and the LabBuddy prototype (chapter 4). It gives an integrated access to all information resources needed during the laboratory class. Furthermore, it can stimulate students to prepare laboratory experiments by presenting laboratory methods as activating exercises. ExperD offers the functionalities as described in chapters 3 and 5. LabBuddy and ExperD cooperate, e.g. the laboratory methods present in ExperD are loaded automatically in LabBuddy, students can adjust their bookings in LabBuddy and countdown timers present in LabBuddy are also shown in ExperD. LabBuddy and ExperD also offer various functionalities for supervisors, enabling them to support students and to stay updated about their progress. Because labEPSS is highly configurable, it can be used in many different laboratory classes throughout curricula.

Samenvatting

Het onderzoek beschreven in dit proefschrift gaat over het ontwerp, de realisatie, de implementatie, het gebruik en de evaluatie van een *electronic performance support system* voor de practica van levensmiddelenchemie (labEPSS). Dit onderzoek is verricht bij het Laboratorium voor Levensmiddelenchemie (LoFC) van Wageningen Universiteit.

Hoofdstuk 1 vormt de introductie tot het proefschrift. Studenten werken met complexe voedselsystemen en geavanceerde apparatuur tijdens de practica van levensmiddelenchemie. Deze apparatuur is nodig om de componenten in het voedsel te isoleren, karakteriseren en modificeren. Voor het onderzoek beschreven in dit proefschrift zijn 4 ontwerpdoelen opgesteld. Ten eerste moet het labEPSS cognitieve overbelasting vermijden, die veroorzaakt wordt door het instructieformat van het practicum. Ten tweede moet labEPSS studenten laten voorbereiden op de experimenten die ze tijdens het practicum uitvoeren. Ten derde moet labEPSS zowel de communicatie tussen studenten onderling, als de communicatie tussen studenten en docenten ondersteunen. Ten vierde moet labEPSS studenten de vrijheid geven om hun experimenten te plannen, zonder dat de begeleiders van het practicum de controle verliezen en ook zonder dat apparatuur wordt overboekt. Om deze doelen te bereiken zijn meerdere webgebaseerde *tools* ontwikkeld.

Hoofdstuk 2 beschrijft het ontwerp, gebruik en evaluatie van een webgebaseerde practicumhandleiding (webLM). Het hoofddoel van de webLM is om studenten te ondersteunen terwijl ze in het laboratorium aan het werk zijn. Dit doet webLM door het aanbieden van *just-in-time* procedurele informatie. De webLM is in 2008 geïntroduceerd tijdens het practicum van het B.Sc.-vak 'Food Chemistry' van Wageningen Universiteit. Iedere practicumgroep had toegang tot een computer met internetverbinding op de labtafel. Naast de elektronische versie kregen studenten ook een geprinte versie van de practicumhandleiding. Uit de evaluatie bleek dat zowel studenten als begeleiders positief stonden tegenover de webLM. Studenten hadden bovendien een sterke voorkeur voor de webgebaseerde handleiding boven de geprinte versie, en vinden eerstgenoemde handleiding gemakkelijk in het gebruik. Sommige begeleiders vinden dat de webLM studenten er onvoldoende toe aanzet om de geboden informatie tot zich te nemen. Het is daarom een interessante ontwerpuitdaging om de webLM interactiever te maken. Tenslotte bleek dat de webLM een veelbelovende *tool* kan zijn om het gedrag van studenten tijdens het practicum te volgen.

Hoofdstuk 3 beschrijft het ontwerp, gebruik en evaluatie van een webgebaseerde experimentontwerper (ExperD). ExperD ondersteunt studenten tijdens het ontwerpen van een onderzoeksstrategie voor hun practicum. Ook ondersteunt ExperD studenten tijdens het uitvoeren van die strategie, doordat de *tool* hen laat zien welke proeven ze uit moeten voeren, en wat de relatie is tussen experimenten. Het gebruik van ExperD is geëvalueerd in de 2009- en 2011-editie van het practicum van het vak 'Food Chemistry'. Beide evaluaties laten zien dat studenten ExperD behulpzaam vinden en dat begeleiders ExperD een waardevolle toevoeging vinden geven aan het practicum. Uit de gebruikersstatistieken bleek dat studenten ExperD gedurende het gehele practicum gebruiken en dat ze hun onderzoeksstrategie *up-to-date* hielden. Tenslotte bleek de ExperD een veelbelovende *tool* te zijn om de ontwerpactiviteiten en het praktische werk van studenten te *monitoren.*

In hoofdstuk 4 wordt verkend in welke mate *smartphones* en *tablets* studenten kunnen ondersteunen tijdens het practicum. Er verschijnen steeds meer mobiele *apps* op de markt, die studenten ondersteunen tijdens het practicum. In een zogenaamd *multiple app supported* practicum, gebruiken studenten verschillende apps voor verschillende taken, zoals bijvoorbeeld het maken van een berekening voor een verdunning. In de praktijk zal dit leiden tot een situatie waarin informatie verspreid is over verschillende schermen en gedrukte materialen. Een dergelijk *multiple app supported* practicum kan onhandig worden zodra studenten meer *apps* gebruiken voor verschillende taken. Met name de noodzaak om te schakelen tussen *apps* is een mogelijke bron voor onnodige cognitieve belasting. In dit hoofdstuk wordt de web app 'LabBuddy' beschreven. LabBuddy biedt een geïntegreerde presentatie van informatie. Een prototype van LabBuddy is gebruikt en geëvalueerd in een practicum. Op basis van de evaluatie worden ontwerpeisen gegeven voor LabBuddy. De uiteindelijke *app* zou door middel van een *responsive layout* moeten werken op alle apparaten die HTML5 webpagina's kunnen weergeven, onafhankelijk van schermgrootte. Ook zouden studenten gemakkelijk moeten kunnen schakelen tussen apparaten waarop

LabBuddy draait. Tenslotte moet LabBuddy een geïntegreerde representatie van informatie geven.

In hoofdstuk 5 wordt een casestudie beschreven, die plaatsvond in het practicum van het M.Sc.-vak 'Food Ingredient Functionality'. Zogenaamde onderzoekspractica zijn geschikt om bepaalde academische vaardigheden aan te leren, zoals het ontwerpen van de onderzoeksstrategieën en het zelfstandig kunnen uitvoeren van onderzoek. Vanwege hun open karakter kunnen onderzoekspractica moeilijker te managen zijn dan meer gesloten practica, ook wel 'kookboekpractica' genoemd. Een door computers ondersteund leerscenario is ontwikkeld om met de organisatorische uitdagingen van het ontwerppracticum van het vak 'Food Ingredient Functionality' om te kunnen gaan. Centraal in dit leerscenario staat een uitgebreide versie van ExperD, die de reserveringen van apparaten afhandelt en de voortgang van studenten in de gaten houdt. Uit de evaluatie blijkt dat het leerscenario succesvol was. Op basis van de evaluatie worden aanbevelingen gedaan om het leerscenario te verbeteren. Bovendien worden suggesties gedaan voor een mobiele webpagina, die practicumbegeleiders in staat stelt om de voortgang van studentengroepen te monitoren.

In hoofdstuk 6 wordt een totaalontwerp van labEPSS voorgesteld. Dit ontwerp bestaat uit LabBuddy en ExperD. LabBuddy is weer gebaseerd op webLM (hoofdstuk 2) en het prototype van LabBuddy (hoofdstuk 4). De *tool* geeft studenten een visueel geïntegreerde toegang tot alle informatie die ze nodig hebben tijdens het practicum. Daarnaast kan het studenten stimuleren om hun experimenten voor te bereiden door de practicummethoden aan te bieden als interactieve oefeningen. ExperD biedt de functionaliteiten zoals beschreven in hoofdstuk 3 en 5. LabBuddy en ExperD werken bovendien samen, bijvoorbeeld doordat LabBuddy de practicummethoden toont die aanwezig zijn in ExperD, doordat studenten boekingen kunnen aanpassen in LabBuddy of doordat *countdown timers* in beide *tools* zichtbaar zijn. De beide *tools* bieden docenten mogelijkheden om studenten te ondersteunen tijdens het practicum en om *up-to-date* te blijven met betrekking tot de voortgang van individuele groepjes. Omdat labEPPS op vele manieren te configureren is, kan het systeem gebruikt worden in verschillende practica in verschillende curricula.

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Completed training activities

Discipline specific courses
ED-MEDIA conference 2008, incl. oral presentation
ED-MEDIA conference 2012, incl. oral presentation
EduSupport Lunch workshops, incl. oral presentation (2 times)
EduSupport onderwijsdag (2 times), incl. oral presentation (1 time)
'NPSO jaarbijeenkomst' 2011
'Onderwijspracticum onderwijskundig onderzoek', Open University, Heerlen
Oral presentation ICAB conferentie 2012
SURF onderwijsdagen, 2007

General courses
Career assessment
Competence assessment
Philosophy and ethics of Food Science and Technology
Project & time management
Scientific writing
VLAG PhD week

Optional courses
Food Chemistry Colloquia
Food Chemistry PhD trip China 2008, incl. oral presentation
Food Chemistry PhD trip, Switzerland and Italy, 2010, incl. oral presentation
Food Chemistry Seminars 2007-2012
Food Chemistry study trip, Ghent Belgium 2009, incl. poster
Organization PhD trip China
Preparing PhD proposal

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