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Design and Evaluation of Digital Assignments on Research Experiments within Food Chemistry

Julia Diederen,[1] Harry Gruppen,[1] Rob Hartog,[2] and Alphons G. J. Voragen[1,3]

Laboratory classes are regarded as an important learning activity, but they also have shortcomings: laboratory classes are often an inefficient learning activity for students and often do not sufficiently support students in developing research specific cognitive skills. It is hypothesized that some of such skills can be achieved more effectively with digital assignments than with laboratory classes. Therefore, three digital assignments have been designed, developed and evaluated. The assignments have three goals: (1) providing a situation in which students can practice research specific cognitive skills and (2) offering a research method which students can also use in a real laboratory situation and (3) providing the possibility to come across a number of common pitfalls. The assignments are described in detail. Results of a first evaluation of the use of the assignments indicate that the students consider the assignments challenging and valuable. The examination results demonstrate that students are quite capable of making a research design. Although students indicate to have learned a useful research method, students do not apply the method in the laboratory classes.

KEY WORDS: chemistry; design of experiments; science education; computer-based learning; learning material.

INTRODUCTION

The main goals of science education at universities are (1) *learning the scientific content*, which is 'acquiring and developing conceptual and theoretical knowledge' (Hodson, 1992), (2) *learning the scientific methodologies*, which is 'developing an understanding of the nature and methods of science and an awareness of the complex interactions between science and society' (Hodson, 1992), and (3) *learning the scientific activities*, which is 'engaging in and developing expertise in scientific inquiry and problem solving' (Hodson, 1992).

Within chemistry education the goals *learning the scientific methodologies* and *learning the scientific activities* are supported during laboratory classes (also called practicals, laboratories, or labs) and thesis projects. Laboratory classes are generally regarded as an important educational activity. Therefore, at traditional universities in the Netherlands for natural sciences in total about 35% of the curriculum is spent on laboratory classes (including experimental bachelor and master thesis projects) (Meester and Kirschner, 1995). Laboratory classes are useful for (Gooding *et al*., 1989; Justi and Gilbert, 2002; Kirschner and Meester, 1988; Meester and Kirschner, 1995; Polanyi, 1969):

[1]Laboratory of Food Chemistry, Department of Agrotechnology and Food Sciences, Wageningen University, Wageningen, The Netherlands.
[2]Wageningen Multi Media Research CentreWageningen University, Wageningen, The Netherlands.
[3]To whom correspondence should be addressed; e-mail: fons.voragen@wur.nl

- learning and developing psycho-motoric skills (such as pipetting, using glassware, and precise weighing of chemicals)
- illustration and concretisation of the theory and for experiencing real phenomena
- learning to discern natural facts from artefacts and learning the impact these artefacts can have, such as the impact of (incorrect) human procedures and instruments
- gaining tacit knowledge (knowledge which cannot be transmitted by prescription (written or spoken) and which cannot be specified in detail)
- motivation, since students enjoy practical work, which is important for interest in science.

The use of laboratory classes as an educational activity has two main shortcomings: (1) laboratory classes are often an inefficient learning activity for students and (2) some for research important cognitive skills are often underexposed. These shortcomings will be explained now in more detail.

Laboratory classes are often an inefficient learning activity for students, or as Kirschner and Meester (1988) stated: ‘For students, the skills and knowledge gained from this work (i.e. laboratory classes) is small in comparison to the time and effort spent to gain this knowledge’. One reason for an inefficient situation is that during laboratory classes students make several mistakes, which can be called pitfalls, causing delays and frustrations. A pitfall related to laboratory research can be defined as follows: *A pitfall is an unforeseen difficulty that occurs during laboratory research due to lack of knowledge, skills and experience, which results in inadequate planning and performance*.

Domin (1999a) showed that several research specific cognitive skills are often underexposed in laboratory classes, probably because many laboratory classes focus on completing experimental procedures at the expense of acquiring these cognitive skills. Examples of these research specific cognitive skills are designing experiments, formulating hypothesis, judging the value of experimental results, and establishing relationships between results.

Because of these two shortcomings, it is of importance that teachers know exactly which learning objectives they can achieve efficiently with laboratory classes, so they can organize the laboratory classes in such a manner that it becomes an efficient activity. The other learning objectives need to be supported with other learning activities. Moreover, it can be useful to make students more aware of the pitfalls during the laboratory classes.

Many teachers tried to find a way to prepare students for the laboratory classes, to guide students in the process after experimenting, or to replace laboratory classes. The following approaches were found in literature related to chemistry education (not necessarily a complete overview):

- *Pre-labs and post-labs*: Meester and Kirschner (1995) use pre-labs and post-labs as a self-study activity, to prepare the students for the laboratory classes and to analyse the data that are obtained during the experiments. These are primarily self-study activities, which are supported by written materials. The laboratory classes are exclusively used to practice laboratory skills in performing experiments.
- *Video-recordings*: This concerns (digital) learning materials that prepare students for laboratory classes via video-recordings introducing a laboratory exercise with quizzes (McKelvy, 2000), and videos covering specific laboratory techniques (Nicholls, 1999). The videos and exercises focus on the use of laboratory skills and on the theory of the experiment.
- *Virtual instruments*: Waller and Foster (Waller and Foster, 2000) report about the use of virtual analytical instruments through the web, for training on instrument operation as a pre-lab exercise. With these instruments clearly time can be saved in the laboratory. The virtual instruments focus on skills related to the learning objective ‘the use of laboratory skills’.
- *Remote laboratory*: d’Ham *et al.* (2004) describe a computer-based remote laboratory to foster experimental design as a learning objective in laboratory classes. In the remote laboratory, which is designed for high school students, students have to design chemical experiments. Subsequently, the experiment is performed by a robot.
- *Post-lab*: Learning materials for post-lab goals were described by for example Nicholls (1998), who describes a computer program in which students rationalise the results of their experimentation by instructing and testing data-manipulation, instructing the chemistry occurring in the experiments and by reporting authentic results directly from raw data. It is used by first year students, who still need to learn how to deal with data.

- *Data-analysis*: Yates (1998) describes a data analysis exercise, which is used in combination of a real experiment. The exercise is solely on paper, with feedback given by tutors.These approaches show that there are several possibilities to use (supplemental) activities, other than laboratory classes, to foster the training of skills that many laboratory classes lack.

LEARNING OBJECTIVES AND LEARNING ACTIVITIES

For learning objectives related to *learning the scientific methodologies* and *learning the scientific activities*, universities normally provide laboratory classes. To investigate which of these learning objectives really need to be learned within the actual laboratory classroom and which can be learned outside the laboratory classroom, first a list of learning objectives related to laboratory classes has to be assembled by means of a literature study. Subsequently, the learning objectives for laboratory classes need to be investigated for their applicability in several learning activities besides laboratory classes. From this it can be concluded which learning objectives could be learned outside the laboratory classes.

Learning Objectives

Table I gives a list of the main learning objectives for the goals *learning the scientific methodologies* and *learning to do science* of science education. This list is assembled by a literature research on learning objectives. Kirschner *et al.* (1990) performed an extended research on learning objectives of laboratory classes in higher education in The Netherlands. They defined eight learning objectives for laboratory classes, based on the successive steps that a scientist ideally takes when carrying out an experiment. Other authors (Bennett and O'Neale, 1998; Brattan *et al.*, 1999; Garratt and Tomlinson, 2001; Johnstone and Al-Shuaili, 2001; Roberts, 2001) have mentioned objectives of laboratory classes as well. Some of the gathered learning objectives are rather generic. They consist of several (related) skills, which makes them extensive and they are often related to skills that are used in almost all learning activities that students have to undertake during their education. Therefore, these learning objectives are excluded. Examples are learning objectives related to teamwork, problem solving, and critical mindedness. Leaving out these generic learning objectives does not mean they are unimportant. Also more content specific learning objectives, such as 'being able to analyse the protein content of a food sample', are excluded, since these are different for each field or each course. Besides excluding learning objectives, many learning objectives identified by different authors are combined into single learning objectives, because they overlap.

Table I. Main Learning Objectives for the Goals *learning the scientific methodologies* and *learning to do science* of Science Education

Main learning objectives
1. Being able to formulate hypotheses
2. Being able to design (simple) experiments to test hypotheses
3. Being able to use laboratory skills in performing (simple) experiments
4. Being able to interpret experimental data
5. Being able to clearly describe the experiment
6. Getting a feeling of reality for the phenomena
7. Being able to remember the central idea of an experiment over a long period of time

The final list of learning objectives (Table I) is regarded to be the main list of learning objectives for the goals *learning the scientific methodologies* and *learning to do science* of science education.

Learning Activities

According to Clark (1994) there is strong evidence that many, very different types of learning materials or learning activities accomplish the same learning goal. He claims that it is the instruction method that influences learning and that each instruction method could be designed into various types of learning materials or learning activities. In this view choices about learning materials or activities in education should be made for *1. the less expensive* (for the University) and *2. the most cognitive efficient* (for the students) ways to represent and deliver instruction (Clark, 1994).

Costs of Learning Activities

Laboratory classes are regarded as a more expensive learning activity than for example computer classes or lectures, since laboratory classes have high costs of assistance (require more input from technical staff) and use expensive materials (chemicals, glassware, equipment, etc.). Moreover, laboratory rooms are regarded as more expensive than lecture or computer rooms, since the costs per square meter per student are higher than for lecture or computer rooms.

Cognitive Efficient

Laboratory classes are regarded indispensable for the learning objectives 'being able to use laboratory skills in performing (simple) experiments' and getting a feeling of the reality for the phenomena' (Table I). Laboratory skills cannot (or hardly) be learned outside the laboratory, although students can be prepared for these skills outside the laboratory as was shown by the several pre-lab approaches within education in the introduction of this manuscript.

Through the activities report writing and giving presentations, which are both often deployed as post-laboratory activities, it is assumed that students learn to 'being able to interpret experimental data' and to 'being able to clearly describe the experiment'. It highly depends on the support and feedback that students receive during these activities whether these activities are actually efficient for these two learning objectives. With lectures or self-study activities without feedback it will be hard for students to train the skills related to the learning objectives in Table I. With computer classes, in which students work on computer assignments, students can work actively and can train several cognitive skills. Therefore, firstly, it is hypothesized that with computer assignments achievement of the following learning objectives can be supported adequately: 'being able to formulate hypotheses', 'being able to design experiments', and 'being able to interpret experimental data'. Secondly, it is hypothesized that computer assignments can also be used to prepare students for laboratory classes by letting students come across a number of pitfalls, which are regarded as the main pitfalls that slow the efficiency of laboratory classes.

Based on these hypotheses it is decided to develop computer assignments with which students can achieve the three just mentioned learning objectives and with which students can come across a number of pitfalls. The incorporation of these three learning objectives and pitfalls in computer assignments implies that these assignments will contain both pre-lab and post-lab activities, which makes them a total research experience apart from the actual performance in the laboratory. These assignments could therefore be called *digital assignments on research experiments*.

DIGITAL ASSIGNMENTS ON RESEARCH EXPERIMENTS

The intended digital assignments on research experiments have three goals:

- they provide a situation in which students can develop the three learning objectives being able to formulate hypotheses', 'being able to design experiments' and 'being able to interpret experimental data'.
- they provide the students with a research method which students can also use in a real laboratory situation.
- they provide students with a possibility to come across a number of pitfalls which are regarded as the main pitfalls that reduce the efficiency of laboratory classes.

In total three assignments were designed and developed. The first two assignments take care of the first two goals mentioned above. The third assignment takes care of the third goal. This manuscript will now continue with explaining the design guidelines for the design of the digital assignments, followed by a thorough description of the assignments. Finally, the evaluation of these assignments will be explained and the evaluation results will be discussed.

GUIDELINES FOR THE DESIGN OF THE ASSIGNMENTS

The method used for the design of digital learning material, such as the intended assignments, comprises the use of design guidelines, as described by Diederen *et al.* (2003). Table II lists the design guidelines for the assignments. These design guidelines will be described now in detail.

Instruction Style

Domin (1999b) presents in his 'taxonomy of laboratory instruction styles' four prevalent styles: expository style, inquiry style, discovery style, and problem-based style. In the case of the inquiry style, the procedures that students follow are student generated, the style holds an inductive approach (the observation of specific situations to learn the general principles), and it holds an undetermined outcome. The inquiry laboratory style gives students the opportunity to engage in authentic activities and has been proven to be

Table II. Design Guidelines for the Design of Digital Assignments on Food Chemistry Research Experiments

Design Guidelines	
Instruction style	g1: Base the assignments on the inquiry instruction style.
	g2: Provide guidance and draw attention to mistakes or wrong decisions made by students.
Research method	g3: Provide the students with a simplified research method which they can also use themselves when performing research.
Authenticity	g4: Provide an authentic context, by offering the physical environments of a real researcher: the desk, the library and the laboratory.
	g5: Relate to the research area of the field of the subject matter: offer an authentic assignment.
	g6: Give an overview of the different activities that are performed in research within the field of the subject matter.

'g' stands for guideline. When a guideline is mentioned in this manuscript a reference to its number as given in this table is provided.

beneficial in fostering critical thinking (Domin, 1999b). Furthermore, the following cognitive skills are related to the inquiry instruction style: hypothesizing, explaining, criticizing, analysing, judging evidence, inventing, and evaluating arguments (Raths *et al.*, 1986). So, with an inquiry instruction style research specific skills such as formulating hypothesis, designing experiments and drawing conclusions can be trained (Domin, 1999b). For these reasons, the inquiry laboratory instruction style is regarded as an appropriate instruction style for the digital assignments on research experiments (guideline g1).

According to Kirschner and Huisman (1998) there is a difference in the use of computers within science and the use of computers within education. Within science, computers aid theory-building, while within education computer programs should be designed to facilitate effective learning. To be educationally effective, a computer program should contain some form of guidance. The second difference between science and education, that Kirschner and Huisman (1998) stress, is that within science in the laboratory new discoveries are done, while for students the laboratory is intended for learning. Therefore, teachers should not ask students to do science so that they will (re)discover facts, but should teach students how to do science. These two remarks are important when incorporating an inquiry style in a computer program. The situation should not be as open as an inquire style prescribes, but should contain guidance and draw the attention of the students to mistakes or wrong choices or decisions in the design of the research (guideline g2).

Research Method

The assignments should provide the students with a research method, which students can also apply in a real laboratory situation (guideline g3). To do this, first an educational sound research method needs to be developed. This research method should include the many activities that scientists perform, such as formulating hypotheses, designing experiments, and interpreting experimental data. Most of these activities are explicitly or implicitly present in a common model of scientific research, which is the Hypothetico-Deductive (H-D) model of the research process (Good, 1999). The H-D model illustrates several aspects of scientific practice. According to this model, scientific theory is a body of hypothesized laws from which observational consequences are deduced. Scientific theory is tested by checking whether the observational consequences correspond with reality. Based on this H-D model an educational appropriate research method that is used for the design of the assignments is developed, which is shown in Figure 1. The research method in Figure 1 is at first developed for the achievement of specific learning objectives and not for teaching students philosophy of science. It is a research method for students, who can be seen as novice researchers.

This research method consists of 9 steps. These steps together describe one research cycle consisting of the main activities that researchers perform during scientific research. The first 4 steps are preparation steps (reading and formulating hypothesis) and are related to the learning objective 'being able to formulate hypotheses' (Table I). Step 5 is related to the learning objective 'being able to design experiments' (Table I). According to a survey at 22 universities, 'designing experiments' is regarded as the main educational objective for laboratory classes (Kirschner *et al.*, 1990). Step 5 of the research method should, therefore, get special attention in the learning material. Step 6 is put between brackets since this step is not a learning objective of the

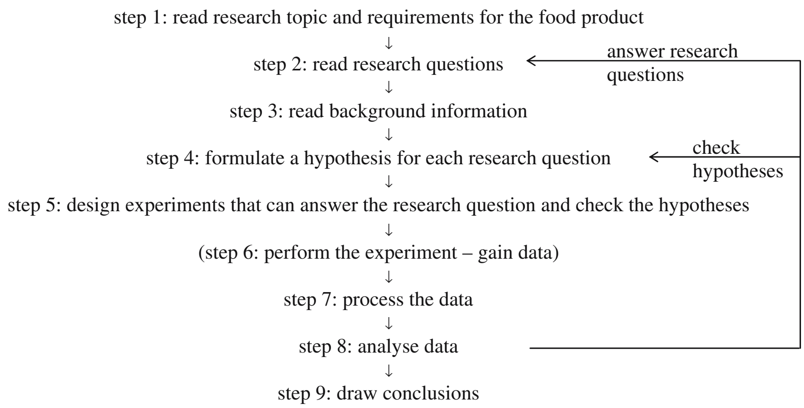

Fig. 1. Research method for the assignments on research experiments.

intended digital assignment and students will, therefore, not 'perform' the experiment in the assignment. The data need to be provided to students after finishing step 6. The steps 7, 8, and 9 are related to the learning objective 'being able to interpret experimental data' (Table I).

Authenticity

Authenticity is related to an authentic context (to reflect the way the knowledge will be used in a real-life situation) and to authentic activities (Herrington and Oliver, 2000). To provide an authentic context each assignment need to be divided into three environments, which are the main working environments of a real researcher: the desk, the (virtual) library and the laboratory (guideline g4).

- *Desk*: At his/her desk normally a researcher thinks about research questions, discusses with other researchers, comes up with theories/hypotheses and processes the data gained from the experiments. Also, researchers draw conclusions, answer their research questions, check their hypotheses and write reports at the desk.
- *Library*: In the library, the researcher will find information related to the research topic: earlier findings, general knowledge, and all kinds of background information. The researcher needs this information for example to formulate hypotheses and to explain the results of the experiments. Nowadays researchers less and less spend time in a real library building. They rather search for information or literature via web-based electronic search engines for electronic scientific manuscripts. Still, this virtual environment on the internet can also be regarded as the 'library'.
- *Laboratory*: Although researchers normally design their experiments at their desk, this activity is strongly related to manual activities that people perform in the laboratory, where the experiments are performed. The methods that researchers are using are related to equipment and chemicals that are available in the laboratory. Therefore, designing the experiment need to be placed in the laboratory. Also, the data gained after finishing an experiment should be provided in the laboratory part of the digital learning material.

To experience an authentic situation, the experiments that students have to design should be based on experimental methods, equipment and chemicals that are actually being used in laboratories. Furthermore, the results students receive after designing the experiments should be based on research data gained from real experiments performed by experienced researchers. To relate the subject matter of the assignments to the research area of the field of the subject matter (g5), a description of this area is needed.

Due to the fact that real laboratory experiences are time consuming, students can only perform one research topic and as a consequence they will learn only a small set of experimental methods. To overcome this, the assignments should bring students in contact with different research topics and should give an overview of the different activities that are performed for different research topics within the field of the subject matter (guideline g6). To be able to give an overview of the different activities, a list of experimental activities performed by researchers in this field is needed.

DESCRIPTION OF THE ASSIGNMENTS

On the basis of the design guidelines listed in Table II in total three assignments on research experiments have been designed and will be described below. This description applies to each assignment. In the third assignment, which has been designed in order to give students the possibility to come across a number of pitfalls, the actions that students have to take are different from the first and the second assignment. A more extended description of this third assignment will follow at the end of this part of this manuscript.

Incorporation of the Inquiry Instruction Style

The assignments should be based on the inquiry instruction style, as described by guideline g1. This means that both the outcome and the procedure are not predetermined. A computer program that does not predetermine both the outcome and the procedure is often called a simulation: students can make any choice and the computer shows the results of the choices. This is hard to do for experiments that are performed within food chemistry research. Within food chemistry many procedures are a combination of methods that are already used for years and have, therefore, evolved into effective methods. Simulating each procedure is, therefore, less useful and time-consuming. Furthermore, in scientific literature only results from experiments with which the intended outcome is reached are published, while, to be able to simulate each procedure, results on ''wrong'' experiments would be needed as well.

To base the assignments on the inquiry instruction style, without using computer simulation, the assignments have the following characteristics.

- Students have to make a complete design of the experiments to make sure that the procedure is student generated (one of the characteristics of an inquiry style). By using feedback, it is explained why a choice, that the student has made, is wrong or that the choice is maybe possible in practice, but a different choice is preferred.
- Students are not learning the research method by studying the method, but by applying the research method in specific situations. Each assignment is a specific situation in which the same research method is used. This induces the inductive approach, which is characteristic for the inquiry style.
- Students are not answering questions. There is no sequence of questions or tasks that are numbered on the screen and one task is not automatically followed by a next task. Students have to find out themselves which task follows another task. These measures induce that students do not get the feeling they are answering an array of questions, but that they understand that they are working in a scientific process.
- The assignments make sure that students do not get stuck, that frustration is low, and that students learn from their mistakes. This is done by giving guidance (feedback) on the student' answers, via drawing attention to mistakes or wrong decisions made by students and giving suggestions on how to proceed (guideline g2).

Incorporation of Authenticity

The field of the subject matter of the assignments is food chemistry. Food chemistry can be defined as a field which focuses on the composition of food, properties and structure of food components, (bio) chemical changes of food components, and the effects of processing, storage, and handling of food (according to the definitions of Belitz *et al.*, 2004; Christen and Smith, 2000; Fennema, 1996; Hultin, 1997; Ruiter and Thier, 1997). The research performed within the field of food chemistry is shown in Table III. The emphasis of research within food

Table III. Research Performed within the Field of Food Chemistry

The research area of food chemistry holds four components (Fennema, 1996):
Determining those properties that are important characteristics of safe, high-quality foods
Determining those chemical and biochemical reactions that have important influences on loss of quality of foods
Integrating knowledge of those characteristics and influences i.e. determining how (bio)chemical reactions influence safety and quality
Applying this knowledge in various situations encountered during formulation, processing and storage of food

chemistry is on (bio-)chemical reactions and how these reactions influence the quality of food products.

To investigate which experimental activities are performed by researchers within certain research areas of food chemistry, a list of experimental activities is developed based on the activities described in several doctoral theses from 1999 to 2004 from the Laboratory of Food Chemistry of Wageningen University (The Netherlands) (Table IV). The main experimental activities that food chemists perform are isolation of components, characterisation of components and modification of components or applications within food systems.

To design the authentic content of the assignments a bottom-up approach has been used, starting with the results of real experiments and ending with research questions. First, a literature research was performed to find useable results from several experiments. From this, several experiments were selected that could be suitable for the assignment. A relation between the experiments was sought to make a single research project containing several research questions, since it should be able to answer these research questions by means of the experiments selected by the designer. The topic of an assignment, which is part of the context in which the students are going to work, is described in accordance with the research questions.

Three assignments were developed to give an overview of the different experimental activities that are performed within food chemistry research (guideline g6) and to be able to relate to the research areas of food chemistry (guideline g5). Since proteins, carbohydrates and lipids are the major food components, it was decided to develop an assignment for each of these food components. This resulted in a topic on soy proteins, a topic on sunflower oil and sage aroma, and a topic on lemon pectin. Table V shows that the research topics of the assignments are related to all experimental activities from Table VI.

Incorporation of the Research Method

The research method as represented in Figure 1 was used as a basis for the assignments to be able to meet guideline g3 (should provide a research method which students can also use themselves in a real laboratory situation). This research method consists of 9 successive steps. The assignments are divided into three environments (the desk, the library and the laboratory), as was prescribed by guideline g4 (should provide an authentic context). The 9 steps of the research method are incorporated into these three environments.

Steps 1 and 2

The first two steps 'research topic and requirements' and 'research questions' of the research method are located in the desk environment. The reason why students are provided with the research questions and why they do not describe the research questions themselves is because the research questions predict which experiments need to be designed

Table IV. Experimental Activities Related to Certain Research Areas within Food Chemistry

Main Activity	Specific Activities*
Isolation	Isolation from several sources (seeds, tubers, fruits, etc.)
	Purification
	Measuring composition/purity
	Measuring extractability/yield
	Analysing the quantity/content
Characterisation	Analysing the composition as a function of various conditions (e.g. pH, ionic strength)
	Analysing the molecular structure as a function of various conditions
	Analysing molecular properties (e.g. size, charge) as a function of various conditions
	Measuring techno-functional properties (e.g. foam formation, emulsion stability)
	Measuring the existence of (chemical or physical) interactions between components
	Measuring effects of (chemical or physical) interactions between components
Modifications or applications	Applying modifications: chemical/enzymatic
	Characterisation of the modified component
	Measuring the effect of the modifications
	Preparation of samples/structures (solution, emulsion, dough, gel, foam)
	Measuring the characteristics of the structures

*Activities are performed for the food components such as proteins, carbohydrates, lipids, enzymes, phenolic components, and their derivates.

Table V. The Description of the Research Topic of the Assignments and the Relation with the Experimental Activities in the Field of Food Chemistry

Assignment	Research topic of the Assignment	Experimental Activities (Table VI)
Assignment 1: Protein	Study the properties of *soy proteins* (as a whole) and soy glycinin for their possibility to replace milk proteins in a yoghurt drink. Isolation yields, solubility of isolated proteins, gel strength, gel structure and water holding capacity of the gels need to be researched for two different pH conditions and three ionic strength conditions.	Isolation from source Measuring composition/purity Measuring extractability/yield Analysing the quantity/content Analysing molecular properties as a function of various (environmental or process) conditions Measuring techno-functional properties: gels (formation and stability) Preparation of samples/structures (solution, gel) Measuring the characteristics of the structures
Assignment 2: Lipid/aroma	Study the possibility to prevent lipid oxidation in a barbeque sauce (20% *sunflower oil*) with a *sage extract* compared to the antioxidant BHT. Moreover, study the usability of the packaging material LLDPE when the oil content of the sauce is decreased, with respect to loss of sage aroma components to the packaging material. The extracted oil should be characterised for its composition before sage is added.	Isolation from source Measuring extractability/yield Analysing the quantity/content Analysing the composition Analysing molecular properties as a function of various (environmental or process) conditions Measuring the existence of (chemical or physical) interactions between components Measuring effects of (chemical or physical) interactions between components Preparation of samples/structures (solution, emulsion)
Assignment 3: Carbohydrate*	Study the possibility to replace gelatine with lemon pectin as a gelling agent in the manufacturing of gummy bear candies. The lemon pectin is isolated, analysed, enzymatically modified, and gels are prepared to determine visually whether the pectin is strong enough to retain water.	isolation from source measuring composition/purity analysing the quantity/content analysing the structure measuring techno-functional properties: gels (formation and stability) preparation of samples/systems (solution, gel) measuring the characteristics of the systems applying modifications: chemical/enzymatic characterisation of the modified component measuring the effect of the modifications

*The actions that students have to carry out in the third assignment are different from assignment 1 and 2, as will be described below.

and executed. The experiments that students are going to design in step 5 (and the related results) are already selected by the developer (for reasons that will be explained below). It is very well possible that students write research questions that can not be answered by the outcome of the experiments selected.

Steps 3 and 4

The third and fourth step of the research method, 'read background information' and 'formulate a hypothesis for each research question', are to be executed in the library and the desk environments, respectively. All information that students could need in order to understand the research topic and to formulate hypotheses is present in the library. When applicable, a hyperlink is made between certain specific terms in the desk and in the library. This saves time for searching for information and also encourages students to read the information. In former evaluations with other digital learning materials it was noticed that without these links students are less willing to look up information. This is a form of just-in-time (access to) information (Kester *et al.*, 2001).

Students formulate in their own words a hypothesis for each research question and compare each hypothesis with information given after submitting the hypotheses. The information tells what could make the hypothesis of the student a proper hypothesis.

Step 5

The fifth step of the research method, 'design experiments', is the most challenging one to incorporate into digital learning material. Literature on experimental design' is almost always related to the statistically sound set up of an experiment. This is aimed at finding the lowest possible number of samples that is still sufficiently large to scientifically investigate the influence of different conditions (e.g. Baker and Dunbar, 2000; Beauchamp and Youssef, 1998; Mogavero *et al*., 1969; Morgan, 1995). This is not the kind of experimental design that the assignments are aiming at. The assignments should support the students to learn how to come from a research question to the design of an experiment, which lists all the successive steps that one needs to take when performing an experiment in the laboratory.

To provide students with a method for designing experiments, a design process consisting of four phases as described in Table VI was developed. For assignments 1 and 2, students perform the phases A–D in the laboratory environment of the assignment. The Figure 2A–D show how these phases are implemented in the learning material.

In phase A, in order to define the experiment(s), for each research question students choose the main

Table VI. The Phases A–D of the Step design experiments' of the Research Method

Design Phases	Reasons and Actions in this Design Phase	Result of the Activity
Phase A: Define the experiments	To define the experiments, students should indicate for each research question the most important experimental steps that need to be taken to answer the research question. In this way students translate a research question into one or more experiments.	A short description of one or more experiments for each research questions
Phase B: Put experiments in order	The experiments described in phase A need to be put into a logical order. For example, an isolation procedure of a component is often needed before performing a structural characterisation of that component. Experiments that consist of nearly the same steps need to be placed next to each other, since these experiments can often be combined into one single experiment.	An order of the experiments and possibly less experiments than resulted from phase A because of combining of experiments.
Phase C: Choose methods	Often several methods exist that can be used to perform an experiment or to do analyses. It depends on for example the research requirements, the desired data, the intended accuracy, the environmental properties, and the characteristics of the sample which method is (most) applicable. Students need to learn that often several methods exist and that they have to make a rationalized choice between these methods. For each experimental step chosen in phase A students have to choose from a large list of methods which method they will use to perform this step. Some steps need a sequence of methods.	The necessary method or methods for each step (identified in phase A) in the experiments that resulted from phase B.
Phase D: Make a final design	Each method can be described as a sequence of procedures, often finished with an analysis. On basis of the methods chosen in phase C, students are going to make a design for each experiment. This design is from start to end a description of all successive procedures that need to be taken. Procedures that students can choose from are described as equipment and chemicals. The final design is still not a plan in time or a protocol, which are both often much more specific. (Making a plan or protocol is (1) too time consuming and (2) largely dependent on the laboratory situation.)	For each experiment an extensive design is made which is good enough to prepare yourself for carrying out the experiment in a laboratory.

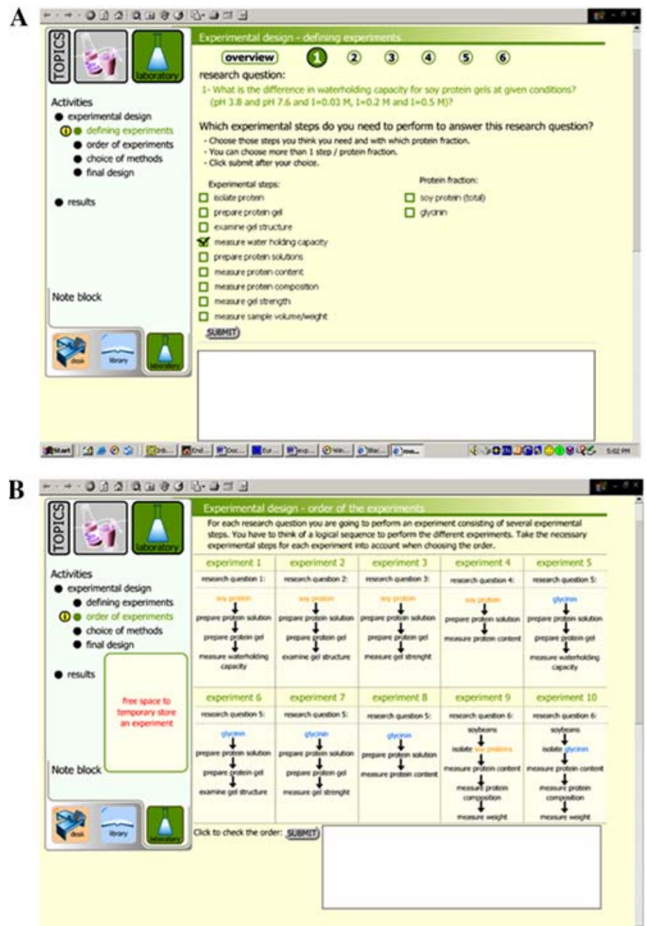

Fig. 2. (A) Defining the experiments (phase A of the experimental design). (B) Putting the experiments into a logical order (phase B of the experimental design). (C) Choosing of methods for the different steps in the experiments (phase C of the experimental design). At this moment the user is dragging the method Dumas' down. (D) The final design of the experiments (phase D of the experimental design). The large figure on the left shows an extended design. The small field on the right side shows that the field with all experimental procedures is first empty.

experimental steps for the experiment by selecting the steps with a mouse click (Figure 2A). In phase B students put the in phase A defined experiments into the desired order. This in done by dragging and dropping the experiments (Figure 2B). In phase C students choose experimental methods for each experiment. They do this by dragging and dropping a method from the list of methods on top, to a step in the experiment (Figure 2C). To be able to make a choice between the different methods, information about each method is provided.

Before explaining phase D, first an explanation of the general lay-out of an experiment is given with the help of Figure 3. An experiment consists of experimental steps (student selects these steps in phase A). Each step consists of one or more methods (student selects the methods in phase C). Each method consists of one or more procedures, which the student selects in phase D.

Performing an experiment in the laboratory is in fact performing a sequence of procedures. A procedure is a sequence of actions to reach a single goal. An example of a procedure is centrifuging milk in a high-speed centrifuge. The actions in this procedure are amongst others filling the centrifuge tubes, putting them in the centrifuge, closing the centrifuge, setting the desired parameters (e.g. time, centrifugal force, and temperature), taking the tubes out of centrifuge and separating the two layers developed during centrifuging.

A procedure is applied to a sample and each procedure leads to one or more products (represented

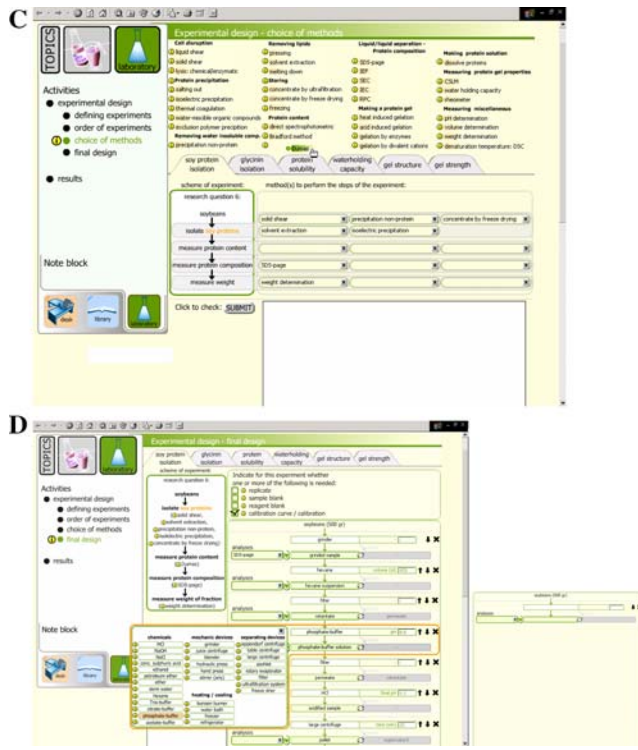

Fig. 2. Continued

by the curved and grey arrows in Figure 3), of which some are regarded as waste (represented by the solid grey arrows in Figure 3). For example, the products of centrifuging raw milk are (skimmed) milk and milk fat. When the goal of this separation is removing fat from milk, then the milk fat is regarded as waste.

The product of the procedure is often the starting point, the sample, for a following procedure. For example the skimmed milk is used in the next procedure in which acid is added to change the solubility of the milk proteins.

The result of a procedure, the product, can be analysed. An analysis can also be regarded as a procedure, only the result is most often a qualitative or quantitative data point (represented by the dotted grey arrows in Figure 3). In the case of the skimmed milk, this milk could be analysed for protein concentration with a Nitrogen analyser, which results in

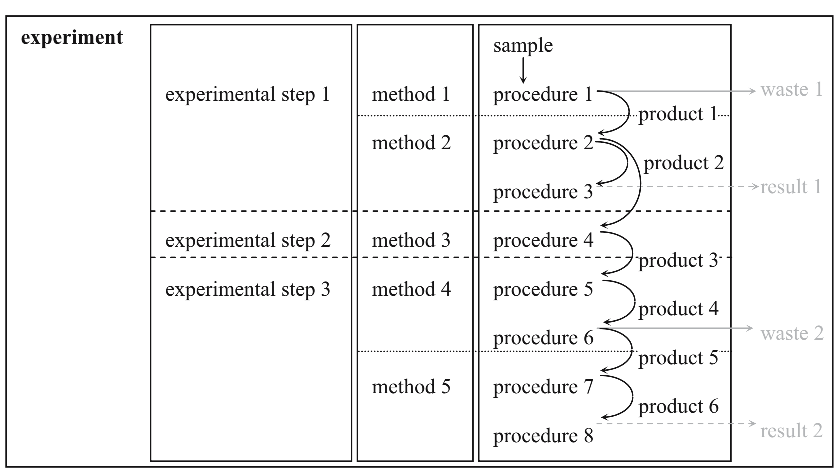

Fig. 3. The general lay-out of a laboratory experiment.

a quantitative number: the nitrogen content of the skimmed milk out of which the protein content can be calculated.

To implement the lay-out of an experiment (Figure 3) into Phase D of the experimental design, the following set up is developed. Students start the design by opening a procedure-element (see the right field of Figure 2D, the small screen). Such a procedure-element consists of a 'procedure-box', a 'product-box', a 'waste-box', and one or two 'parameters'. A student can fill the boxes of this procedure-element by clicking on the procedure-box in the procedure-element (as is done for one procedure-element in Figure 2D). An option menu appears from which the student can choose between several chemicals or equipment. When the student clicks on one of the options the boxes of the procedure-element are filled by the computer program: the procedure-box, the product-box and, when applicable, the waste-box. Furthermore, it is possible that students are requested to fill in a parameter for the procedure, e.g. to indicate the volume of the added chemical. When the procedure results into two products, one is selected as product' and the other as waste'. Students can swap these two boxes to assign the other result as waste. Clicking on the product-box will make it possible to apply an analysis to the product. Again an option menu appears containing several analyses from which the student can choose. Several analyses can be applied to the same product. Next, a second procedure-element can be opened. The product of the first procedure is the starting point for the second procedure. Finally, when all the necessary procedures have been put into a sequence and all the necessary analyses are assigned to the appropriate products, a final design is developed.

Information that students might need during phase D is made available to them in several ways:

- The methods that a student has chosen in phase C are made visible on the screen in phase D (see Figure 2D). An information button is enclosed for each method.
- Information is accessible about the equipment, chemicals and analysis in the option menus for the procedures and analyses.
- Students can submit their answers anytime. Subsequently, feedback is given to their design: wrong choices are explained and suggestions for how to proceed are given. Feedback is always top-down: feedback will be given to the first wrong choice from the top of the design.

Steps 6 and 7

The sixth step of the research method, 'perform the experiment', is a virtual step. After finishing the final design for an experiment, the results of this experiment are provided to the students. The results are presented in the same way as when the students would acquire them in a real laboratory environment. For example, the result of a water holding capacity test of a protein gel is the visual appearance of a centrifuge tube with a water layer on top of a pressed gel. Therefore, this result is also presented visually to the students.

The results are also delivered to the students in a MS Excel® file. These data spreadsheets decrease the effort for students to process the data, which is the seventh step of the research method. In this step students are asked to calculate several numbers, such as the yield, percentages or concentrations. Just-in-time information is available on how to perform these calculations. Furthermore, within the feedback, hints are provided to guide students in the calculation process.

Step 8

Step eight is 'check hypotheses and answer research questions'. Students are presented with their own hypotheses. For each hypothesis they have to select the processed data with which they want to make a graph. With this graph they can check the hypothesis. To check the hypothesis they can choose to: verify the hypothesis, falsify/reject the hypothesis, or keep the hypothesis, but need a new experiment to check it. Furthermore, students have to answer the research questions in so far possible. This is done with a text field in which students can write down their answer.

Step 9

In the last part of the assignment, 'discussion and conclusions', an overview is given of the main conclusions about the performed research. The answers that students gave to the research questions are set besides the conclusions of an experienced researcher, and students have to compare these two. At the end of this part of the program, students have to give a main conclusion in the form of a multiple-choice question. The assignment is finalized with the overall conclusion of the research.

THE THIRD ASSIGNMENT

As explained before, the third assignment is different from the first two assignments with respect to the actions that the student has to perform in this assignment. This assignment is also called the pitfall' assignment. To make sure that students are more aware of these pitfalls during the laboratory classes, students come across a number of pitfalls within the third assignment.

To come up with the most important pitfalls to incorporate in the third assignment, first a short investigation has been done with teachers ($n = 5$) and teacher assistances ($n = 29$, PhD-students and laboratory technicians) of the Laboratory of Food Chemistry. They were asked to come up with at least 3 pitfalls, based on their experiences with laboratory classes. In total 40 pitfalls were identified. Subsequently, the same persons and a group of Food Technology Master students ($n = 29$) were asked to select 10 pitfalls from this list of 40 pitfalls, which they regard as most important to them. From this, 11 pitfalls were selected to be incorporated in the third assignment.

In the third assignment, a fictitious person called Susan had completed all the design phases of the experiments needed to answer the research questions of the topic. In the results of these experiments it is clear that the experiments of Susan did not work out well, since the results look odd or impossible. It is the task of the students to find out which mistakes Susan has made during the design phases and to correct these. After each valid correction the results are adjusted and finally, after correcting each pitfall, the students can finish the third assignment by checking the hypotheses of Susan and drawing conclusions. At the end of the assignment, after drawing conclusions, a list of the pitfalls is provided to the students.

The set-up of the third assignments is equal to the first two, with the exception that students can only change something in the design of the experiments by selecting in the results section which phase of the experimental design they want to correct. Feedback explains whether their change was useful or not, and gives a hint on how to proceed, if necessary.

EVALUATION

The digital assignments have been evaluated during the course Advanced Food Chemistry (6 ECTS) at Wageningen University. In the first three weeks of this course, 36 students followed lectures during 8 afternoons (24 contact hours) and five afternoons on computer classes in which students work on the assignments (20 h): two for the first assignment, two for the second assignment and one for the third assignment. For the computer classes, students were divided over two rooms, respectively 16 and 20 students, with in each room one supervisor. Each student had a computer at his/her disposal.

The second three weeks of this course were spent on laboratory classes (60 h) in which students worked in pairs on one research topic. The research topic corresponded with the topics of the computer assignments, some were even nearly equal. In total four supervisors were present. Students wrote a report about their research findings and gave a presentation to their fellow students.

To evaluate the assignments, students were asked to fill in two types of evaluation questionnaires and students were tested on their ability to design one or more experiments to answer a research question during the examination. Finally, the assignments, and their relation with the laboratory classes, were evaluated during an interview with 9 students, an interview with 2 lecturers and an interview with the coordinator, as well as supervisor, of the laboratory classes.

The Questionnaires

The two questionnaires that students were asked to fill in are a specific questionnaire and a general course questionnaire. The specific questionnaire was filled in at the end of the laboratory classes and the second questionnaire after completing the examination of this course. The specific questionnaire contains several statements related to the quality of the course and course activities (lectures, laboratory classes and computer classes), on the quality of the assignments, on the learning effect of the assignments, and on the relation between the assignments and the laboratory classes.

Most of the statements in the specific questionnaire need to be judged on a 5-point Likert scale, valued totally agree, partially agree, neutral, partially disagree and totally disagree. Students could also choose I can not give a judgement'. To process the results the answers on the 5-point scale questions were transformed into numbers: 5 for totally agree, 4 for partially agree, 3 for neutral, 2 for partially disagree and 1 for totally disagree. For each statement an average for all students is calculated, together with the proportion of students that agreed with the statement (totally or partially agree). Students who answered I can not give a judgement' on a question were excluded for that question.

The second questionnaire, is a questionnaire that is regularly used in many courses at Wageningen University to investigate the quality of courses. Answers to the questions that are important for the evaluation of the assignments are taken into account in this evaluation. Most questions in this questionnaire are also statements that need to be judged on a 5-point scale, valued 1 to 5, 1 anchored as disagree and 5 anchored as agree. For these statements also an average and a percentage of students that agreed with the statement (that answered 4 or 5) are calculated.

The Examination Question

As stated above, one part (12.5 %) of the examination is related to the assignments. Students received a research question, requirements and conditions of a research topic, a list with chemicals and equipment and some background information. Students were asked to

a. Define a hypothesis for the research question with an argument why this is a possible answer to the question.
b. Design one or more experiments by using a selection of the chemicals and equipment. Students are asked to explain their choices.
c. Explain the use of a replicate', sample blank, reagent blank, and calibration/calibration curve' and whether they will need these for the just designed experiments.

The answers to this examination question are used to investigate the learning effect of the assignments.

RESULTS AND DISCUSSION OF THE EVALUATION

Characterization of Students

From the 36 students that were provided with the specific questionnaire 24 students completed the questionnaire. To investigate whether the characteristics gender, age, and nationality influence the results of the evaluation, students were asked to specify these characteristics. On average, the answers to the questions of the specific questionnaire showed no or only small but no significant differences between students with different characteristics. From the students who filled in the specific questionnaire 67% were female, all aged between 20 and 26, and 63% hold the Dutch nationality.

Course Quality

When evaluating learning material it is important to know how students perceive the quality of the course and its course activities in which the learning material is evaluated. A poor course situation could negatively influence the judgement of the students about the learning material of interest.

Quality in General

Table VII shows that for lectures as well as assignments and laboratory classes most students said to have learned much or reasonably enough. Moreover, respectively 78, 70 and 70% of the students graded these learning activities with a 7 or higher. From the general course questionnaire (Table VIII) it can be said that students agreed they learned a lot from this course and the overall rating is satisfactory.

Table VII. Learning Effect and Grading of Different Learning Activities According to the Students

How Much Did You Learn From ...	Average* ($n = 24$)	%4/5	%2	Rate Each Learning Activity from 1–10	Rating[a] ($n = 23$)	%7
Attending the lectures?	3.5	50	8	Lectures	7.1	78
Making the digital assignments?	3.6	54	8	Digital assignments	7.3	70
Doing the laboratory classes?	3.5	50	13	Laboratory classes	7.0	70
Studying the book food chemistry?	3.9	62	0**			

*Average is the average for all students on a 5-point Likert scale (5 = very much, 4 = much, 3 = reasonable, 2 = little, 1 = nothing), %4/5 is the percentage of students that that answered 4 or 5, %2 is the percentage of students that answered 2 (no students answered 1).
**11 students did not answer this question, because they did not study or read the book yet.
[a]Rating is the average of all students on a 10-point scale (1 means very poor, 10 means excellent), %7 is the percentage of students that rated the activity a 7 or higher.

Table VIII. Answers to Some Questions of the General Course Questionnaire

Statement	Average (%)*	n
The performance of the lecturers was good	3.6 (58)	33
The teaching in the laboratory classes of this course was good.	3.5 (59)	32
There was sufficient opportunity to practise the relevant skills in the laboratory classes.	3.6 (53)	32
I am satisfied with the computer rooms of the computer classes.	4.2 (80)	25
I am satisfied with the supervision during the computer classes.	4.2 (83)	24
I think I learned a lot from this course.	4.2 (84)	31
Overall rating of the course (taking all aspects into consideration—content, presentation, workload, etc. on a scale of 1 (poor)—5 (excellent)).	3.8 (81)	32

*Average is the average for all students on a 5-point Likert scale (numbered 1–5, 1 = disagree, 5 = agree).
(%) Is the percentage of students that agreed with the statements (% that answered 4 or 5).

From this, it can be said that students are in general satisfied with the learning activities in the course.

Quality of the Computer Classes

According to the answers of the general course questionnaire (Table VIII), students are satisfied with the computer rooms of the computer classes. Furthermore, supervision during the computer classes is perceived as satisfactory by the students, which can be concluded from the answers for both the general course questionnaire (Table VIII) and the specific questionnaire (results not shown). For the specific questionnaire students rated the statement The supervision during the computer classes was good.' with an average of 4.7 (100% answered partially agree or totally agree). The statement Supervision by one person in the room during the computer classes is enough.' was rated with an average of 4.5 (96% agreed).

Quality of the Assignments

According to the results in Table IX it can be concluded that students are most positive about the second assignment. From the interviews with the students it became clear that this difference is due to the fact that the set-up of the second assignment is equal to the set-up of the first assignment. After finishing the first assignment, students know what to expect and what to do in the second assignment.

Clearly, students are not satisfied with the quality of the third assignment (Table IX). Also according to the results of the general course questionnaire (Table X) students are less positive about the third assignments than about the first and the second assignment. During the interview with students it became clear that the frustration when working on the third assignment is high amongst others because some pitfalls were hard to detect. Moreover, it was confusing to some students that although the set-up

Table IX. Quality of the Assignments as Perceived by Students

	First Assignment (n = 24)		Second Assign ment (n = 24)		Third Assignment (n = 24)	
Item	Average*	%*	Average*	%*	Average*	%*
The assignment is clear: I knew from the start what I had to do.	3.6	63	4.2	88	2.9	29
I understood how to work on the assignment.	3.6	67	4.3	88	3.0	29
I liked working on the assignment.	3.8	71	4.3	83	3.3	50
Working on the assignment was NOT frustrating.	3.5	71	4.1	88	2.8	29
The assignment is challenging (it stimulates my thoughts).	4.2	83	4.3	83	3.8	67

*Average is the average for all students on a 5-point Likert scale (5 = totally agree, 4 = partially agree, 3 = neutral, 2 = partially disagree, 1 = totally disagree).
(%) Is the percentage of students that agreed with the statements (% that answered 4 or 5).

Table X. General Course Questionnaire Questions Related to the Quality of the Assignments

Statement	Average (%)*	*n*
The formulation of the ICT instructions was clear and understandable.	3.8 (71)	24
The quality of the ICT material (exercises, sources, blackboard) was good.	3.9 (75)	24
It was useful to use computers in this course.	4.1 (83)	23
The digital assignments 1 is valuable learning material.	3.8 (76)	25
The digital assignments 2 is valuable learning material.	3.8 (72)	25
The digital assignments 3 is valuable learning material.	3.2 (48)	25

*Average is the average for all students on a 5-point Likert scale (numbered 1–5, 1 = disagree, 5 = agree).
(%) Is the percentage of students that agreed with the statements (% that answered 4 or 5).

Table XI. Learning Effect of the Assignments

Statement	Average (%)* (n = 24)
Working on the research cycle during the assignments is for me a useful way of thinking about how to conduct research.	4.1 (88)
I have a more clear view of how research is performed after working on the assignments than before I worked on these assignments.	3.9 (63)
After working on the assignments I know how to formulate a hypothesis.	3.8 (67)
The way I had to design an experiment in the assignments was a logical way of working for me.	4.4 (88)
After working on the assignments I know how to design an experiment.	4.2 (92)
I learned how to interpret experimental data with the assignments.	4.1 (79)

*Average is the average for all students on a 5-point Likert scale (5 = totally agree, 4 = partially agree, 3 = neutral, 2 = partially disagree, 1 = totally disagree), (%) is the percentage of students that agreed with the statements (% that answered 4 or 5)

of the third assignment looks equal to the first two assignments, students have to work with it differently.

Learning Effect of the Assignments

It is expected that with the assignments students learn a method to perform research, and that this method is useful to them. The results from Table XI show that students are quite positive about what they have learned about conducting research and designing experiments. These results support the idea that with computer-based education students can learn about several aspects related to research and science.

Examination

As shown in Table XII, on average students scored 6.6 points out of the maximum possible score of 10 points for the examination question related to the assignments. Moreover, 73% of all students scored more than or equal to 6 points (results not shown). Designing the experiments, i.e. determining a feasible ordering of chemicals, equipment and measurements and handling the research question and the requirements, is not noticed as a problem for the students (question b). It can be concluded that most students demonstrated that they are quite capable of designing an experiment.

Relation between Assignments and Laboratory Classes

According to Table XIII it can be concluded that during laboratory classes students do not put in practice what they have learned during the assignments. Students do not formulate research questions and hypotheses, and they do not use the approach of designing experiments as learned in the assignments. It is noteworthy that students indicate that they have made a research design/experimental design before they started with experiments. This is a clear difference with former years in which it was noticed by supervisors of the laboratory classes that students hardly prepare a design of their experiments.

It can be concluded on basis of Table XIV that students recognised the equipment and methods used during the laboratory classes from the assignments. Also, the third assignment made students somewhat aware of the mistakes that can be made during performing experiments, which is also noticed by the coordinator of the laboratory classes. Although only three students worked on the topic soy proteins, it is noticeable that these students are most positive about

Table XII. Results for the Examination Question Related to the Assignments

Question	Maximum Points	Average* $n = 33$	Standard Deviation**
Question a: define a hypothesis for the research question	1	0.8	0.2
Question b: design experiment(s), explain your choices	6	3.9	1.2
Question c: explain use of replicate, sample blank, reaction blank, and calibration (curve)	3	1.8	0.5
Total for questions a + b + c	10	6.6	1.6

*Average is the average over all students for the amount of points students earned for each question.
**Standard deviation between the students for earned points.

Table XIII. Effect of the Assignments on the Laboratory Classes

Statement	Average (%)* ($n = 22–24$)
I felt prepared for the laboratory classes due to the assignments.	3.3 (54)
Because of the assignments I have a better understanding of what I am doing in the laboratory classes.	3.4 (55)
I clearly noticed a relation between what I have learned in the assignments and what I had to do in the laboratory classes.	3.5 (58)
In the laboratory classes I formulated research questions for the research that I was going to perform.	2.9 (43)
I formulated hypotheses in the laboratory classes before I started with the experiments.	2.7 (39)
In the laboratory classes, I made a research design/experimental design before I started with experiments.	3.9 (75)
During the laboratory classes, the approach I used to design the experiments was the same approach as I learned in the assignments.	3.0 (50)

*Average is the average for all students on a 5-point Likert scale (5 = totally agree, 4 = partially agree, 3 = neutral, 2 = partially disagree, 1 = totally disagree).
(%) Is the percentage of students that agreed with the statements (% that answered 4 or 5).

Table XIV. Effect of the Assignments on the Laboratory Classes, Specifically Related to the Topics in the Laboratory Classes

Statement	Average (%)* ($n = 24$)
During the laboratory classes I remembered the mistakes that Susan made in the third assignment, so that I did not make the same mistake myself.	3.5 (46)
During the laboratory classes I noticed that I made a mistake that also Susan made in the third assignment.	2.1 (65)[a]
The third assignment helped me to remember that I have to be very accurate and careful during performing the experiments.	3.7 (71)
The methods and equipment that I use in the laboratory classes are methods/equipment that I also worked with in the assignments.	4.0 (87)
I looked up information from the assignments while I was working in the laboratory classes.	2.8 (48)
I think that without the assignment it would have taken more time for me to understand and perform the experiments of the laboratory classes.	3.0 (52)
Because of the assignments I already had a good prior-knowledge about my topic in the laboratory classes.	3.2 (50)

*Average is the average for all students on a 5-point Likert scale (5 = totally agree, 4 = partially agree, 3 = neutral, 2 = partially disagree, 1 = totally disagree).
(%) is the percentage of students that agreed with the statements (% that answered 4 or 5).
[a]This is the percentage of students that disagreed with statement (% that answered 1 or 2).

the relation between the assignments and the laboratory classes (results not shown). This laboratory topic was also the topic of the first assignment, which was on soy proteins. The second assignment is also quite the same as the laboratory topic on lipid and antioxidants, but still these students did not feel prepared for their laboratory topic (results not shown).

From the interviews with the students of the laboratory classes it became clear that students feel there is not enough time during the laboratory classes to apply the research method and that they feel that supervisors are mainly 'result directed' and put less stress on the process of research. The interview with the coordinator of the laboratory classes made clear that supervisors do stress the importance of the process of research, but because of the pressure in time and to make sure that students gather enough results to be able to write a reasonable report, supervisors are eager to stimulate students to use their time for executing experiments. This could explain the impression of students that supervisors are indeed only 'result directed'.

CONCLUSIONS

With respect to the first goal of the digital assignments, it can be concluded that the digital assignments provide a situation in which students can train the research specific cognitive skills related to the three learning objectives 'being able to formulate hypotheses', 'being able to design experiments' and 'being able to interpret experimental data'.

For the second goal ('provide students with a research method which students can also use in a real laboratory situation') two conclusions can be drawn. First, a general research method could be incorporated in the assignments and students indicate that this research method is logical and useful to them. And second, students do not use the learned research method, when not asked to do this, in the real laboratory classes. Possibly, both supervisors and students focus on completion of the experiments and the attention to the use of the research method is, therefore, low.

To reach the third goal ('provide students with a possibility to come across a number of common pitfalls'), the third digital assignment was developed. The evaluation results show that this assignment was not judged well by the students on several aspects, but students indicated that this assignment helped them to remember during the laboratory classes that they have to be very accurate and careful. A different lay-out and set-up for the assignment on pitfalls will be developed in the future.

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